PUBLIC AND REGULATORY DYNAMICS WITHIN THE

NUCLEAR POWER INDUSTRY

by

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Bachelor of Mechanical Engineering
Georgia Institute of Technology, 1985

Submitted to the Department of Civil and Environmental Engineering
in Partial Fulfillment of the Requirements for the
Degree of

MASTER OF SCIENCE
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ABSTRACT

Nuclear reactors supply steam for over twenty percent of the United States' electricity generation. Yet, perhaps no other technology has elicited as much controversy. Fears and emotions drive a controversy and debate that originates both in the technical realities of nuclear power and in the psychological and social uncertainties connected with nuclear energy, advanced technology, social power, and modern warfare. Expression of these social concerns comes partly through public protest, through interest group formation and activity, and through governmental oversight and regulation. These different modes of expression represent society's efforts to control the nuclear technology that causes their unease.

The means of social input -- government regulation, group legal interventions, public protest -- have all significantly impacted the nuclear industry. Social mechanisms guide utility operations, affecting safety, performance, and cost. One question that arises is whether the policies and structures in place impact industry performance and social welfare in a positive manner. Do social concerns lead to improvements in nuclear performance and safety? When utilities react to social concerns, do their actions beget more concern creating additional public unease? Are these feedback mechanisms in the public interest?

In creating the Social Pressure, Safety Regulation Model, or SPSRM, this thesis concentrates on the social system and its responses to nuclear performance.

Thesis Supervisor: Dr. Kent Hansen

Title: Professor of Nuclear Engineering

ACKNOWLEDGEMENTS

When one has never written a master thesis, just the concept can seem overwhelming. What subject to undertake, how to approach the chosen topic, how to support the research, and where to receive guidance and support are all of tremendous importance. In my endeavor, I feel extremely fortunate because of the opportunities for learning which this project has opened and the guidance and support that I have received in the process.

To begin, I would like to thank Professor Kent Hansen whose support and guidance has been strong and consistent. When chapters or pages required reading and comment, Kent was always there. Kent in conjunction with The MIT International Program for Enhanced Nuclear Power Plant Safety have financially supported this research and my education for the past year. For this, I am forever grateful.

In addition, I would like to express my appreciation to Dr. Tatsujiro Suzuki and Mr. Taiji Yamaoka both of whom supported and enhanced the work presented here. Dr. Suzuki helped initiated this project and he provided much wise and critical comment. Mr. Yamaoka, a visiting engineer from Chuba Electric of Japan, also provided much help and comment for the development of the Social Pressure Safety Regulation Model. To these gentlemen I am indebted.

Finally, for her companionship both at and away from school, time proofing, and overall support I thank Ms. Jennifer Griffith. She has added a spark to the past year and for that I am grateful.

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Chapter 1

1.0 Introduction

> "Controversy over nuclear energy, both bombs and reactors, has been exceptionally durable and violent, exciting more emotion and public protest than any other technology."
>
> Spencer R. Weart (1991, p. 30)

Nuclear reactors supply steam for over twenty percent of the United States' electricity generation. Yet, as Weart noted, perhaps no other technology has elicited as much controversy. Emotions and fears drive much of the controversy and debate. The public's fears originate both in the technical realities of nuclear power and in the psychological and social uncertainties connected with nuclear energy, advanced technology, social power, and modern warfare. Expression of social concerns over nuclear power comes partly through public protest, through interest group formation and activity, and through governmental oversight and regulation. These different modes of expression represent society's efforts to control a technology that many feel places an unnecessary risk upon the general public.

Government regulation, legal intervention, public protest, have all significantly impacted the nuclear industry. Social mechanisms place restrictions and burdens on utility operations, affecting safety, performance, and cost. Are these restrictions positive? Do social concerns lead to improvements in nuclear performance and safety? When utilities react to social concerns, do their actions beget more concern creating additional public unease? This thesis studies the interaction between the nuclear industry and the social system, trying to identify how industry actions affect public concerns and how these concerns are translated into social action which, in turn, affects nuclear operations. A better understanding of social and nuclear industry interactions might reveal ways of improving industry and social structure and policies to provide safer and more reliable nuclear energy at competitive cost.

1.1 Background

All one hundred and ten commercial reactors operating within the United States are light-water reactors utilizing either a pressurized (PWR) or boiling water (BWR) design. A reactor, like a coal-fire boiler, is a source of heat for the production of steam. Water circulating through the core removes heat produced by fission of the fuel within the reactor core. This heated water produces steam either by boiling at the top of the reactor or by circulating through a heat exchanger called a steam generator. Steam then turns a turbine which spins the generator producing electricity. Thermal/steam systems of similar configuration generate over ninety percent of United States' electricity.

What separates a nuclear power plant from other thermal power plants is the use of nuclear fission to generate heat and steam. Nuclear fission occurs when an atom of a heavy element splits into two or more lighter pieces. Fission may be spontaneous or induced by striking a heavy atom with a neutron. Because the nuclear forces binding the heavier element are much less than those binding the lighter pieces, the splitting of the heavy atom releases tremendous energy. Commercial nuclear reactors primarily utilize uranium 235 with neutron induced fission. Uranium 235 is a naturally occurring but rare isotope of uranium. (Natural uranium contains approximately 99.3% U^{238} and 0.7% U^{235}.) When a uranium 235 atom splits, two or more atoms of lighter elements are produced. In addition, one or more neutrons are released. These neutrons may then proceed to split additional uranium 235 atoms, creating a chain reaction where neutrons released from a prior split proceed to strike and split an additional uranium 235 atom releasing more neutrons which split other uranium 235 atoms releasing more neutrons and so on and so on. If the chain reaction is self-sustaining, not growing or decaying (that is each uranium fission on average produces one additional fission), then the chain reaction is said to be critical. Commercial power reactors operate at criticality. The energy released by uranium 235 fissions heats the cooling water which eventually drives the generator.

The human hazard comes primarily from radiation, which can kill, cause cancer, or damage genetic material. Unstable, energetic atoms often break apart emitting energy, mass, or both. The process of coming apart or emitting energy is called radioactive decay. Although there are many forms of decay, three are most common: alpha decay, beta decay, and gamma decay. Alpha decay occurs when a nucleus spits out two protons and two neutrons (a helium nucleus). Beta decay occurs when an atom spits out a high speed electron. Gamma decay occurs when an atom, instead of emitting mass, releases a burst of electromagnetic energy in the form of gamma rays. Alpha particles, beta particles, and gamma rays are nuclear radiation, and atoms which emit them or materials containing such atoms are said to be radioactive. Harm to humans, or any living thing, occurs when radiation enters or passes through the body and interacts with living cells. The energetic particles or rays can kill or damage living cells. If the genetic structure of normal body tissue is damaged, cancer will sometimes occur. If the genetic structure of reproductive or fetal cells is damaged, birth defects may occur. However, to kill or damage enough cells to immediately kill or serious injury a person requires an extremely large dose of radiation, many orders of magnitude above background radiation. On the other hand, cancer and even birth defects can potentially result from extended exposure to low levels of radiation, on the order of background.

Unfortunately, radiation is an inherent feature of nuclear fission. Radiation may be emitted during the fission process, by radioactive fission products (lighter elements created by the fission process), by radioactive decay products, or by materials irradiated by nuclear radiation. Because shielding and distance virtually eliminate any direct offsite exposure from the reactor vessel, the danger of public exposure comes not from direct radiation being emitted by the operating reactor but from the potential of an accidental offsite release of radioactive material. Although rare, equipment failures and human error have resulted in accidental releases. For over ten days in 1986, radioactive material spewed from the Chernobyl site in the Ukraine causing wide spread exposure and concern: twenty-nine power plant workers and firefighters died of acute radiation exposure and over 135,000 people within a twenty mile radius were evacuated. By far the worst reactor accident in World History, Chernobyl lacked many of the safety systems required in the U.S. However, even in the U.S. small releases have occurred. In 1979, Three Mile Island released small quantities of radioactive gases, producing very small exposures for the general public -- probably less than a third of yearly background exposure (Wolfson 1991, p. 198). By far the worst accident in U.S. History, Three Mile Island released less than a millionth the radiation that Chernobyl did (Wolfson 1991, p. 77).

> Is nuclear power safe? Yes: Multiple safety systems ensure that radiation will be contained even when malfunctions and operator errors occur. Major accidents are possible, but are so unlikely that the risk is negligible. You are far more likely to die in an automobile accident, a fall, or a fire than in a nuclear accident. And no other industry can match the safety record of the U.S. commercial nuclear power enterprise. (Wolfson 1991, p. 209)

Although a nuclear accident may be the public's dominate technical concern with nuclear power plants, there are other technical issues inherent with the nuclear power industry which concern the public. Operating a nuclear power plant produces unwanted radioactive materials. These materials are generally classified as waste and must be dealt with in some manner. Like all hazardous waste, radioactive waste raises environmental and human concerns. Two classifications of radioactive waste exist: high level (highly radioactive) which is primarily spent fuel, and low level (somewhat radioactive), which covers everything from irradiated tools to contaminated clothing. High level waste creates the greatest concerns because it is highly toxic to living beings. Currently in the U.S., no satisfactory means exist for dealing with long term storage of these materials, although a storage facility at Yucca Mountain in Nevada is under investigation. Still of some concern, low level waste is generally buried at low level waste depositories, where it is to remain until no longer an environmental or health threat. Although nuclear power plants are not the only source for both high and low level waste (weapons programs, hospitals, universities, and other sources produce both types), waste is an operational hazard of the industry.

Although the technical hazards associated with nuclear power drive much of the public's concern, the public's fear over nuclear power has many origins. The threat of nuclear bombs and the images of destruction are always present in the nuclear debate. The horror of Hiroshima and Nagasaki combined with the knowledge of mutually assured destruction delicately balanced during the cold war has ingrained a fearful image of nuclear technology in peoples' minds. Even though the complete failure of a nuclear power plant could never produce the destruction of a nuclear bomb, the imagery persists. Real connections to the bomb do exist. However, typical commercial reactors are ill suited for weapons development. Bombs require either plutonium or highly enriched uranium, while commercial fuel, although uranium, is enriched only 1 to 3 percent. Spent fuel contains some plutonium which could be remove if reprocessed. However, commercial reactors are not designed for plutonium production, and reprocessing is a difficult and expensive endeavor. Thus, imagery and reality mix to connect the destruction of nuclear warfare to the energy production of commercial power reactors.

Societal perceptions of modern technology and social power also contribute to public concerns over nuclear power. The impersonality of the machine, the regularity of modern industrial society, and the complexity of advanced technologies alienates many within the public. This general frustration and hostility toward the advances of technology is projected onto the nuclear industry. Aversion to the centralization of social and political power also becomes symbolized in the nuclear power plant as economies of scale have led to huge thousand megawatt concentrations of electric power generation. As Weart asserted, "Reactors became a condensed symbol for all modern industrial society." (Weart 1991, p. 35)

The building and operation of a nuclear power plant presents a highly charged public controversy. As discussed, real risk and the imagery of nuclear technology combine to create public concerns and fears. These in turn drive social efforts to control and direct this technology.

1.2 Problem

The public and nuclear utility do not function in separate worlds. Social actions driven by public concerns and fears significantly affect the functioning of a nuclear power plant. Utilities spend tremendous quantities of time and resources addressing social concerns. This includes interacting directly with the public and groups expressing specific public concerns along with satisfying governmental regulation and oversight. The question is how and in what manner do social concerns affect the nuclear plant? Will the interactions between the nuclear utility and the social system provide nuclear safety and inexpensive electricity?

Certainly, public opposition has influenced the nuclear industry. Public protest combined with legal interventions by public interest groups significantly hampered efforts to bring on-line the Seabrook Power Station in New Hampshire and the Shoreham Nuclear Power Station on Long Island: construction permits were issued in 1976 for Seabrook and 1973 for Shoreham, yet operation of Seabrook did not begin until 1990 and Shoreham was scrapped in 1988 after completion of construction but without ever being fully operational. Regulatory changes instituted after Three Mile Island also contributed substantially to the long construction delays. Additionally, Rancho Seco near Sacramento was shut down following a public forum in the late 1980s, and Yankee Atomic's recent decision to shut down Yankee Rowe in Western Massachusetts was heavily influenced by public and intervener group opposition. Obviously, public concerns play a role in the nuclear debate. But what are the mechanisms? Do social factors affect operations beyond the licensing process and how?

The International Program for Enhanced Nuclear Power Plant Safety, a project within MIT's Center for Energy and Environmental Policy Research, is sponsoring research to study the nuclear industry's interactions with the social system. This effort seeks to better understand how the social system, which is external to the nuclear utility's management and operation, impacts plant safety and performance. The goal of the overall project is to model the functioning of the nuclear plant and its interactions with the external world, perhaps finding how best to interact with that world.

This thesis seeks to model how the social system responds to the operation of a nuclear power plant. It is a piece of the more comprehensive effort to study the general dynamics between the nuclear industry and the external world. The objective is not to develop a precise prediction of the social system but to gain a better understanding of social behavior in response to the functioning of the nuclear industry and the nuclear industry's response to social behavior.

1.3 Method

The focus of this thesis is the development a system dynamics model of the social system interacting with the nuclear industry. The social organizations and interactions comprising the public, government, and nuclear power industry present a complex system with many information-feedback paths. System dynamics adapts information-feedback theories from control systems engineering for studying complex social systems such as the nuclear plant, society connection. It provides a means to simulate the complex, inter-connectivity of human endeavors.

The system dynamics approach to modeling has been translated into commercially available software packages that facilitate developing models of specific systems. One such package, Stella II®, was used in this thesis.

The overall model development began with an effort to represent the cause-effect relations between aspects of nuclear plant operations and the social/political systems external to the plant. The result of the process is a so-called "causal loop" diagram. Development the causal loop diagram was an iterative process. At each stage of development, experts in the nuclear industry reviewed the representation of cause/effect relationships in the model, suggesting modifications when appropriate. This development occurred in 1992 and 1993. After completing the causal loop diagram, these ideas were converted into a explicit mathematical model using the Stella II® program. Subsequently, the mathematical model was used to generate a host of numerical simulations of system behavior. The overall model has four segments as illustrated in Figure 1.1. This thesis is concerned with the Social Pressure / Safety Regulation segment.

The next chapter presents a brief overview of the system dynamics method to acquaint the reader with how models are created and represented. Chapter 3 presents the details of the SP/SR model including the Stella II® representations. Chapter 4 shows some results of a few simulations. It should be recognized that these results are preliminary and are merely indicative of how the approach may be used to analyze policy options. Before results can be given credibility, the remaining portions of the model need to be completed and a rigorous validation process undertaken. Chapter 5 reviews possible policy implications. Chapter 6 summarizes the thesis and comments on future directions.

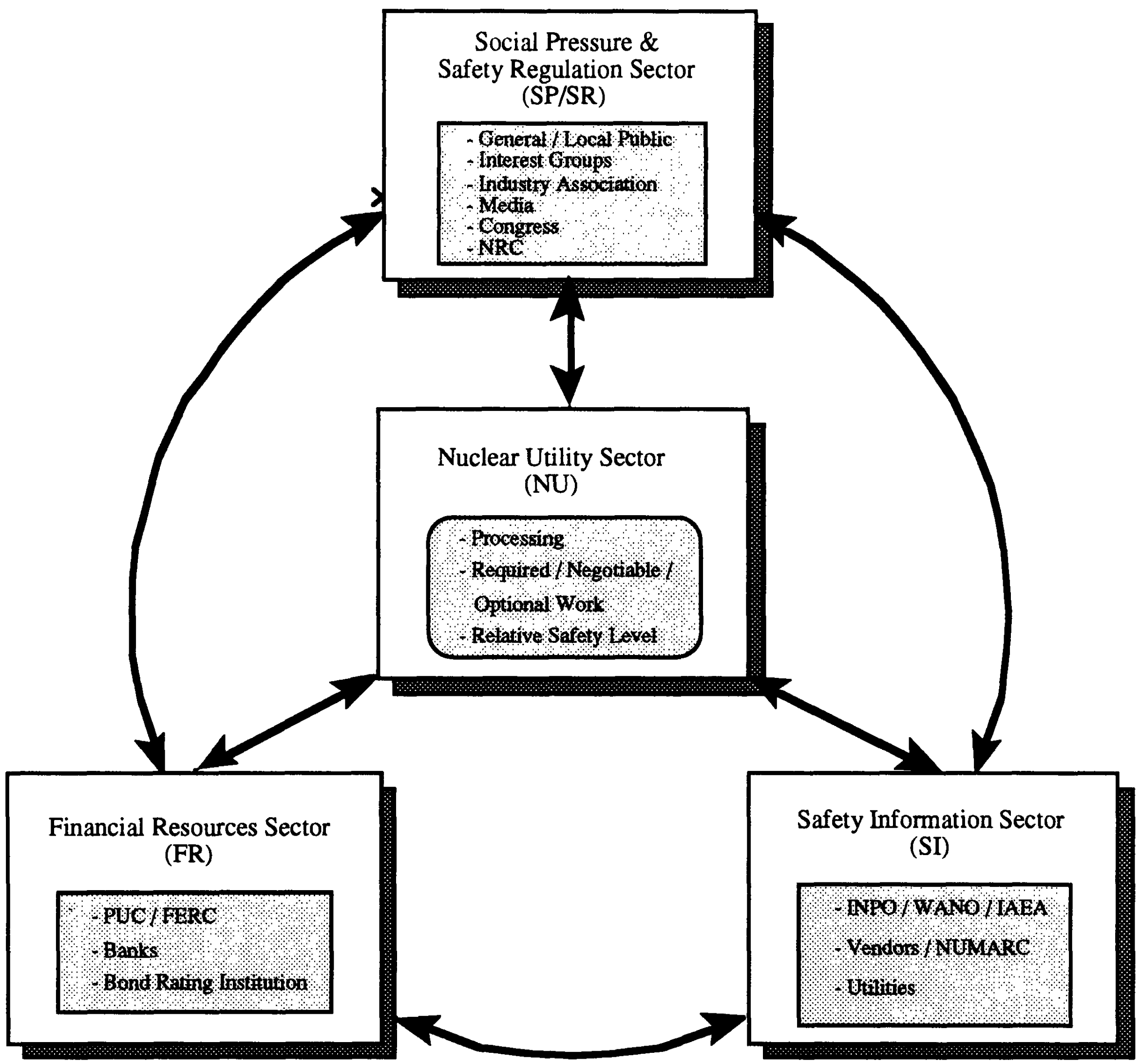

Figure 1.1 Sector Diagram

Chapter 2

2.0 System Dynamics

> "Industrial [System] dynamics is the study of the information-feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of the enterprise."
>
> Jay W. Forrester (1961, p. 13)

In the late 1950s, Jay Forrester and others at the Massachusetts Institute of Technology began applying theories of information-feedback from control systems engineering to the study of modern industrial systems. Since then, system dynamics has been applied to an array of complex social systems. These applications are based on several premises. First, information-feedback is integral to the human decision making process. Humans act in response to the environment. These actions alter the environment creating a new basis for future decisions guiding future actions. Second, human judgment cannot always predict the behavior of complex systems:

> ... The structure of a complex system is not a simple feedback loop where one system state dominates the behavior. The complex system has a multiplicity of interacting feedback loops. Its internal rates of flow are controlled by nonlinear relationships. The complex system is of high order, meaning that there are many system states (or levels). It usually contains positive-feedback loops describing growth processes as well as negative, goal-seeking loops. In the complex system the cause of a difficulty may lie far back in time from the symptoms, or in a completely different and remote part of the system. In fact, causes are usually found, not in prior events, but in the structure and policies of the system. (Forrester 1969, p. 9)

The complexity of markets, businesses, governments, eco-systems, etc. is such that the unaided human mind can not follow cause-effect relationships accurately enough to predict behavior. The third premise follows the observation that most system troubles are created by the internal structure of social systems. People often attribute troubles to external causes when in reality the culprits are the policies and structures within the system. The fourth premise looks to the future with the belief that structural and policy changes can improve system performance. Efforts in system dynamics are undertaken with the belief that a better understanding of system behavior can lead to ways of improving system performance. (Forrester 1961, p. 14)

2.1 Developing The System Dynamic's Perspective

Whenever humans approach a problem, past experiences are applied to the task at hand in hopes of matching this experience with the present difficulty to find a solution. In essence, mental pictures, or models, of how the world works are used to solve the problem before us. The system dynamics methodology presents one picture, or view, of the world which might aid us in solving problems. That view has several characteristics. As stated previously, system dynamics sees the causes of social and organizational problems as originating internally within the social and organizational systems. This implies that the systems under study is closed-looped. That does not mean that a system is all inclusive. However, most systems under study can be identified and separated from the remainder of the world.

Another characteristic of system dynamics is that builds upon the operational aspects of a system. The cause-effect relationships developed within a system dynamics model find their origins in physical realities of the world, not in ambiguous correlations. Finally, system dynamics focuses on patterns of system behavior over the passage of time and not on unique events, even if dramatic.

Identifying the structures and policies of the system as the source of troubling behavior requires that system boundaries be chosen such that what generates the unwanted behavior lies within the system. As an example, suppose the local rabbit population were disappearing. Including only the rabbits in the system might be insufficient to create the population dynamics. However, including the local predator and food supply within the system's boundaries might enable one to create a system model which more accurately depicts the fluctuations within the rabbit population. On the other hand, including sun spots or eruptions of Mount Pinatubo might obscure the most important cause-effect relationships within the rabbit system, even if these events may be remotely connected to rabbit behavior.

Drawing system boundaries is only the beginning. The cause-effect relationships must also be identified. To illustrate this point, ask yourself what causes academic success? (example taken from High Performance Systems 1992, p. 27) Below is a list of several things which may affect a students performance in school.

- motivation
- teaching quality
- intelligence
- attendance
- parental involvement
- physical well-being
- mental well-being
- classroom environment

However, this list alone provides limited information because it provides no structure as to the causality of the system. In addition to asking what causes academic success, one should ask: how? Figure 2.1 graphically depicts the cause-effect relationships among some of the variables listed above.

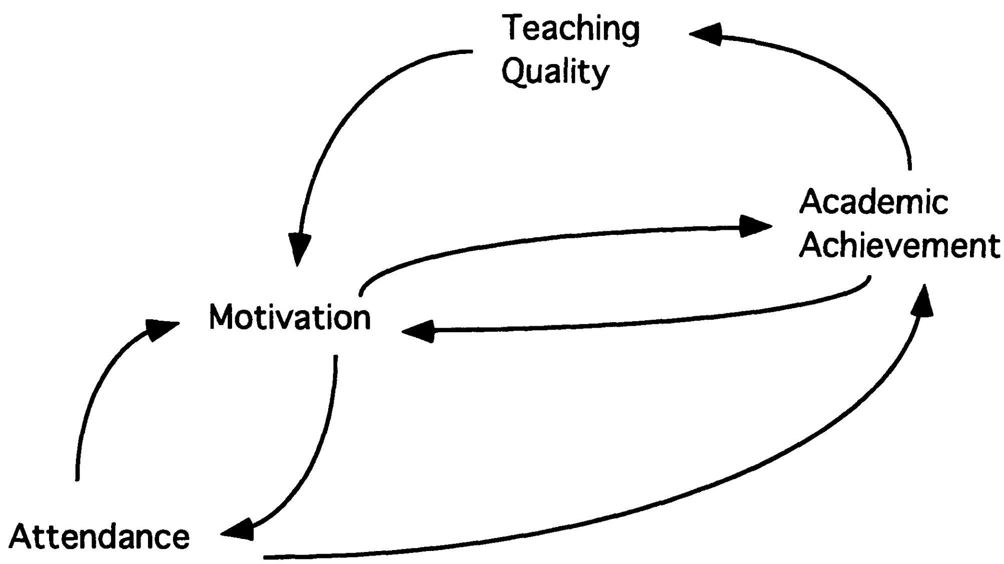

Figure 2.1: Causal-Loop Diagram
Academic Achievement
(High Performance Systems 1992, p. 28)

Figure 2.1 graphically displays a so called "causal-loop" diagram. Within this causal-loop diagram, motivation fosters achievement which then creates motivation: a feedback loop. Teachers notice academic achievement and are themselves inspired to give more time and effort to shinning pupils. This attention increases teaching quality which feeds back to motivate students even more. Attendance follows a similar feedback path. All of these cause-effect relationships are "positive" feedback loops. That is they promote a spiraling upward or downward: more of one causes more of the other which cause more of the first in the upward spiral and vice versa on the downward spiral. Intelligence or mental well-being or parental involvement could create loops which limit these upward or downward spirals: i.e. less motivation or teaching quality might spark more parental involvement. These would be limiting or "negative" feedback loops. Both positive and negative information-feedback are integral to most human endeavors, as this example illustrates.

One thing which separates system dynamics methodology from other modeling techniques is the effort to incorporate the cause-effect mechanisms within the model. For example, an econometric model predicting the price or production of pork bellies may vary only as a function of several macroeconomic variables such as GNP, Interest Rates, Housing Starts, etc.

Pork Bellies = β_1*GNP + β_2*Interest Rates + β_3*Housing Starts +. . .

In these types of linear models, there may be nothing in the equation which actually relates to pigs or the inventory of pork. If one wanted to predict the production of pork, the inventory of hogs might be of importance to the future levels of pork bellies. To use system dynamics, one would take an operational approach. The structure of the system which creates pork bellies would be fundamental to the system dynamic's modeling of production. GNP may have a correlation to pork bellies, but available hogs and breeding stocks along with gestating periods and maturing times are more important to structure future production. System dynamics tries to replicate the operational structure behind the system under study so that the modeler can understand how system structure affects behavior.

Determining how the system behaves and why it behaves as it does are both objectives of system dynamic modeling. It is dynamic behavior that system dynamics seeks to understand. That is, the patterns of pork bellies or of academic achievement over time. The prediction of particular events, such as receiving a grade of A or F in a particular class or the number of hogs slaughtered on May 1st, are not the purpose of this technique. Understanding why academic achievement goes up or down, why pork production increases or decreases, and what time frames are involved are what is important in system dynamics modeling.

2.2 Model Structure

"Stocks and flows are the nouns and verbs of [system dynamics]. Stocks are the 'things'. Flows are the 'actions'." (High Performance Systems 1992, p. 37)

Stocks, or levels, represent accumulations: money in your bank account, hogs in the barnyard, love in one's heart, worries in one's head, people in a city, widgets in inventory. Accumulations are in almost every system. They indicate the status of the system at any particular time: how rich one is or the adequacy of production.

If there is an accumulation of something, that accumulation resulted from some action, a flow. Stocks and flows go hand-in-hand. Nothing can accumulate without flowing. Money cannot enter an account without someone depositing it. Hogs do not mysteriously appear in the barnyard; they are born or purchased. Inventory is produced. Love grows, etc. Flows represent the action of accumulating.

A system dynamics model consists of an assortment of stocks and flows. They are the building blocks of system dynamic models. Stocks, or rather information about stocks, structure the decisions which control system flows. These flows change the status of the system causing new decisions to be made which specify new rates of flow. Such information-feedback creates a complex dynamic directing the system. To illustrate how stocks and flows are pieced together to model a simple system, the next section will step through the building of a simple model of population growth.

2.3 Building a Simple Population Growth Model

The population growth exercise will step through three successions of the model, starting with a linear relationship with no feedback, followed by a simple feedback structure, and finally a limiting feedback loop will be added. Causal relationships for each stage will be presented, followed by a translation of these relationships into the Stella II® model format. System behavior of each stage will be presented after the structure is reviewed.

2.3.1 Linear Population Growth with no Feedback

What causes a population to grow? The primary mechanisms are births and deaths of individuals. The correlation between births and deaths controls whether the population increases, remains stable, or declines. In the real world, many complex interactions control the birth and death rates of any living species. However, to illustrate one could imagine a simple structure where a population grew or declined with a constant number of births and deaths.

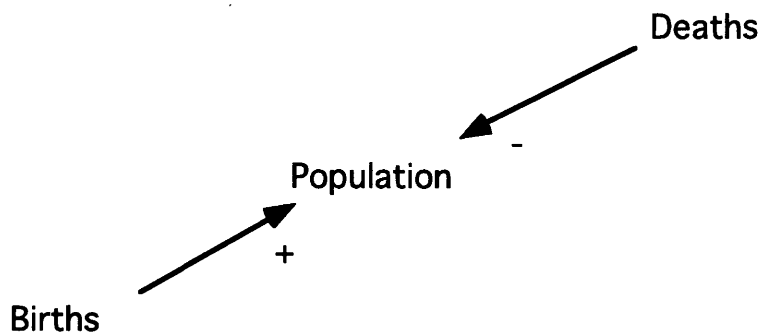

Figure 2.2: Causal Loop Diagram
Linear Population Growth

Figure 2.2 depicts a population whose growth or decline is solely a function of births and deaths, both of which are independent of the population. No feedback paths exist. Figure 2.3 shows the causal diagram in Figure 2.2 translated into the Stella II® format. Population is a stock. Births and deaths are flows. With births and deaths set at constant values independent of population, one would expect a linear growth or decline of the population depending on which rate, birth or death, was larger. This is the case as shown in Figure 2.4. If the initial population is one million individuals and the birth and death rates are 20,000 and 30,000 per year, respectively, a linear decline in population occurs, as shown in Figure 2.4. If the numerical values for births and deaths are reversed, growth occurs, also shown in Figure 2.4.

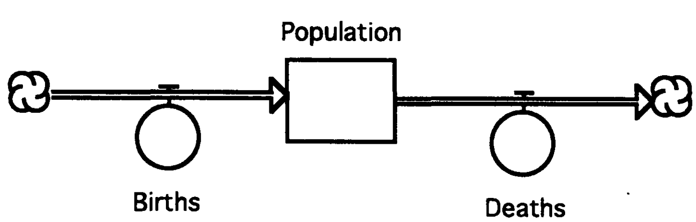

Figure 2.3: Stella II Diagram
Linear Population Growth

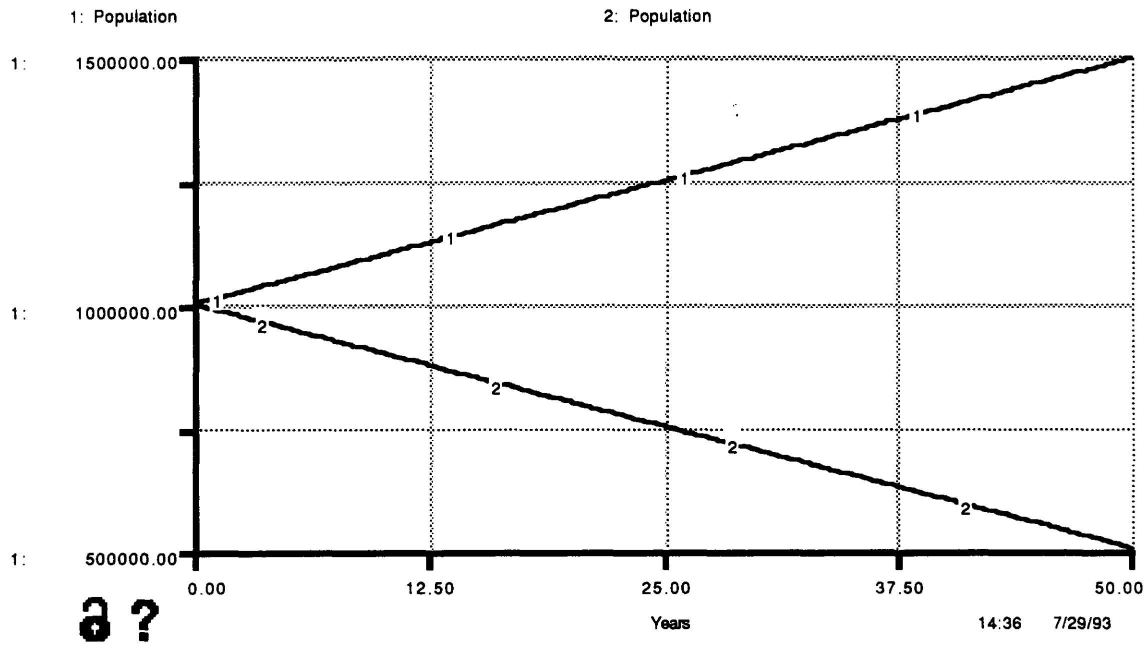

Figure 2.4: Population Growth
Linear with no Feedback

2.3.2 Exponential Population Growth with Feedback

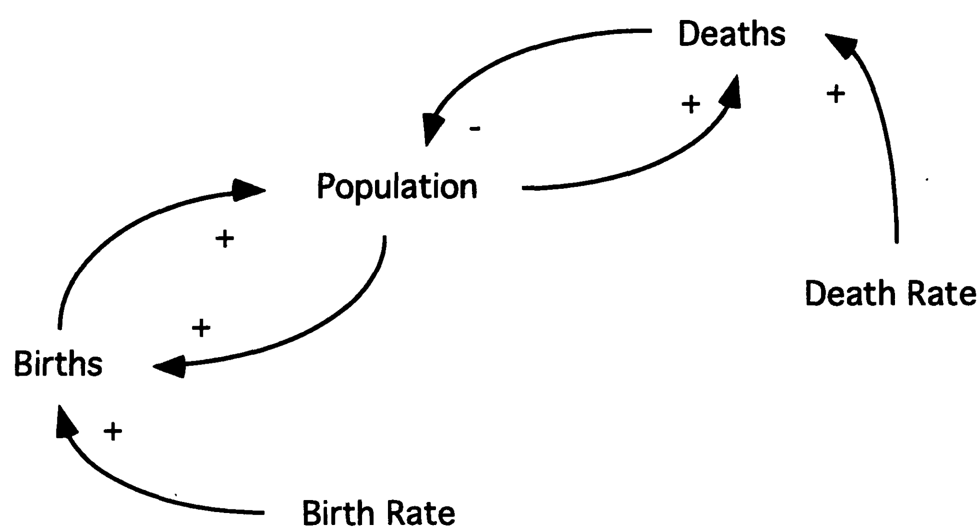

Figure 2.5: Causal-Loop Diagram
Exponential Population Growth

Exponential growth, or decline, results when births and deaths are a function of the population itself. Figure 2.5 shows the feedback loops between births, deaths, and population. Figure 2.6 translates Figure 2.5 into Stella II® format. As before, population is a stock and births and deaths are flows. However, Fig. 2.6 includes two additional converter inputs: birth rate and death rate. These are constant variables which feed into the birth and death calculations. Births equal the population times the birth rate, and deaths equal the population times the death rate.

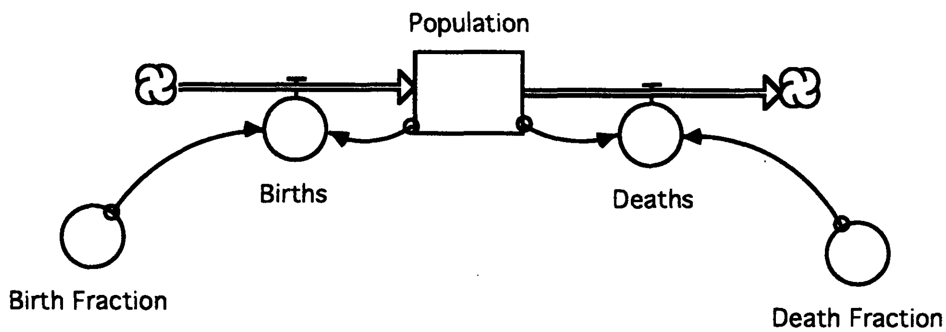

Figure 2.6: Stella II Diagram
Exponential Population Growth

As babies are born, the population grows. However, since births are a function of the birth rate and the population, a growing population experiences an increasing number of births. If the birth rate is greater than the death rate, the positive feedback between births and population will cause the population to grow exponentially, as seen in Fig. 2.7. If the death rate is greater, the positive loop between population and deaths will cause an exponential decline in population, as shown in Fig. 2.8. For exponential growth shown in Fig. 2.7, the birth rate is 0.3 while the death rate is 0.2. For exponential decline shown in Fig. 2.8, the birth rate is 0.2 while the death rate is 0.3.

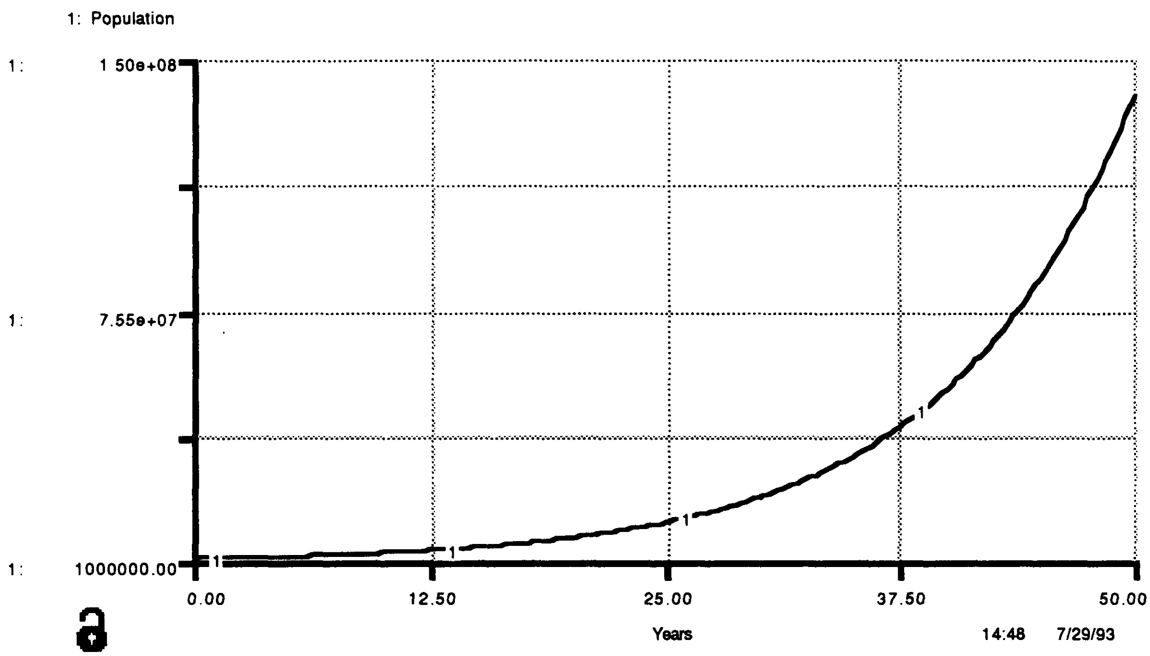

Figure 2.7: Population Growth
Exponential Growth

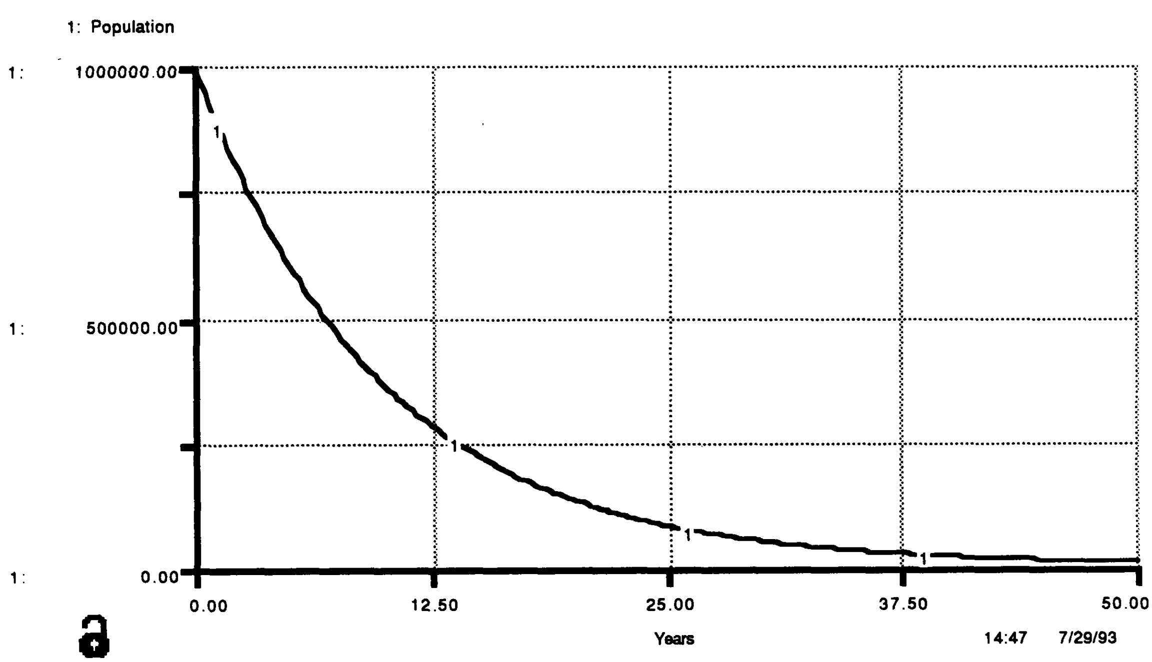

Figure 2.8: Population Growth
Exponential Decline

2.3.3 Population Growth with Limiting Loop

What happens if the population confronts a limited food supply? Figure 2.9 adds the effects of a limited food supply to the population model. The food required to feed the society is a function of the population and is represented by nutrition needs. Nutrition surplus compares the needs of the population to the supply available. The death rate now becomes a function of the nutrition surplus. As the nutrition surplus declines, the death rate increases. This places a negative feedback loop in the model. If the food supply is constant, the nutrition surplus will decrease as the population increases. This causes an increase in the death rate that in turn lowers the population.

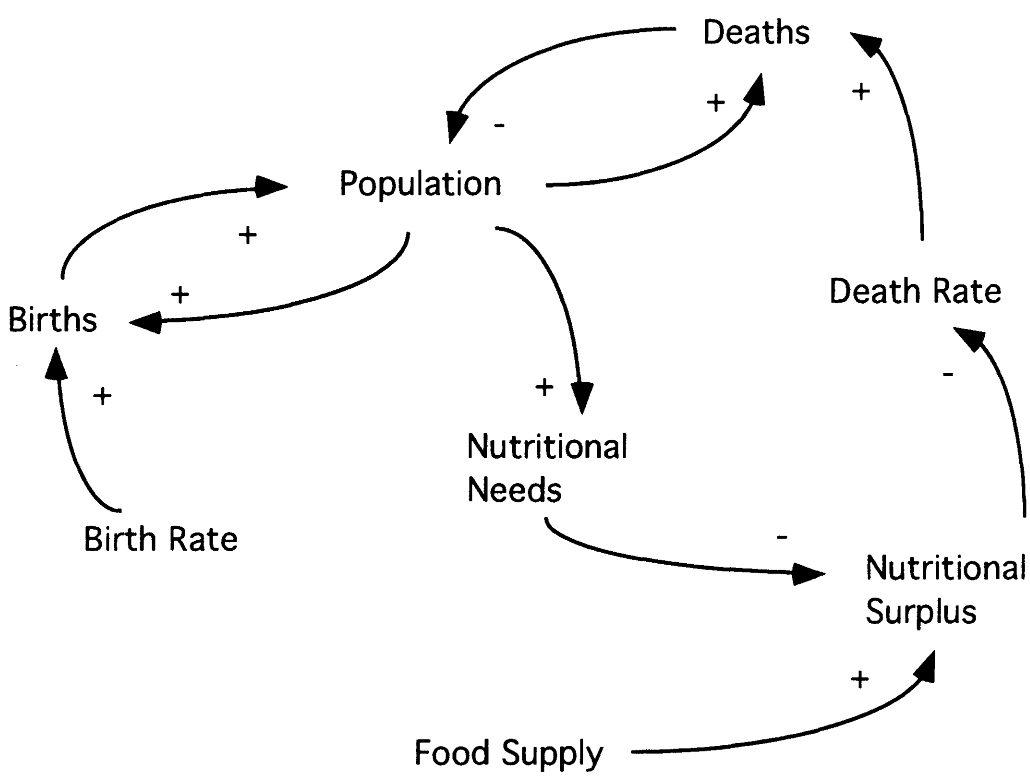

Figure 2.9: Causal-Loop Diagram
S-Shaped Population Growth

Figure 2.10 shows the limited loop translated into Stella II® format. Food supply is an additional stock. Because it is constant, no flows exist. Nutritional surplus and nutritional needs are both converter equations. Within Stella II® converters may supply constant variables, perform mathematical calculations, or provide a graphical relation between two variables. In Fig. 2.10, nutritional needs and nutritional surplus perform calculations, per capita food requirements provides a constant variable, and death fraction relates nutritional surplus graphically to the death fraction. The additional mathematical expressions for this sections are listed below. (**S** - Stock, **O** - Equation or Graphical Converter, **C** - Constant Variable Converter)

O Nutritional Needs = Population * Per Capita Food Requirement

O Nutritional Surplus = Food Supply / Nutritional Needs

O Death Fraction = Graph (Nutritional Surplus)
(0.0, 0.700), (1.0, 0.285), (2.0, 0.159), (3.0, 0.123), (4.0, 0.109), (5.0, 0.109), (6.0, 0.105), (7.0, 0.104), (8.0, 0.103), (9.0, 0.102), (10.0, 0.100)

S Food Supply
Initial Conditions: 6 Million Tons of Food

C Per Capita Food Requirement = 1 Ton per person per year

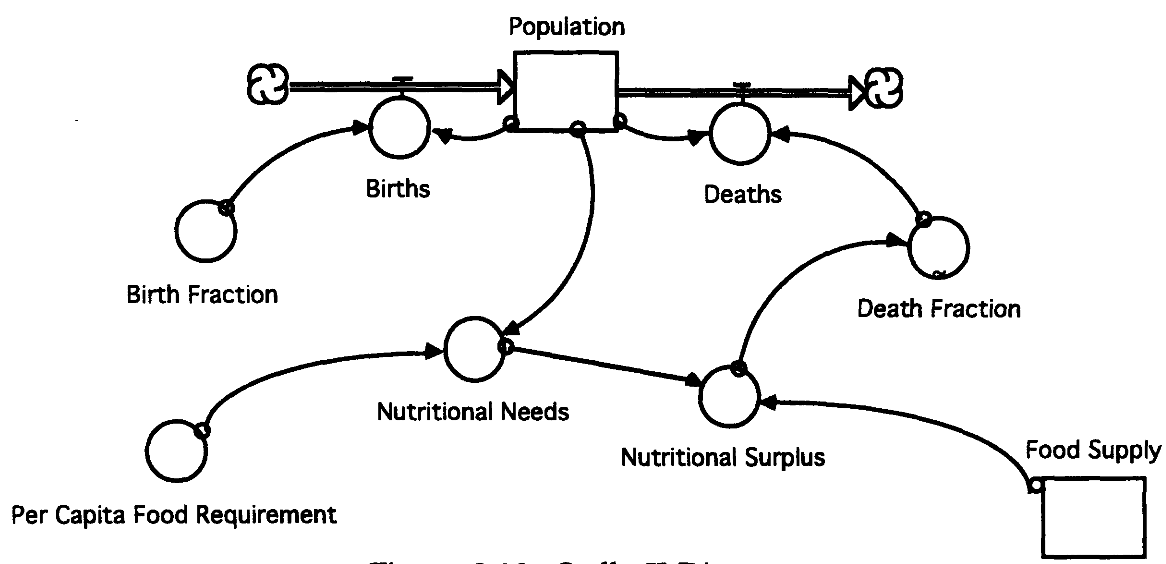

Figure 2.10: Stella II Diagram
S-Shaped Population Growth

Figure 2.11 shows the results including a limited food supply. Initially, when the surplus is large, the population grows exponentially. However, as the population grows, the surplus of food decreases. Consequently, the death rate rises and eventually takes control of the population growth. The result is an S-shaped population curve: exponential growth followed by an exponential approach to a fixed population. The limited food supply eventually constrains population growth.

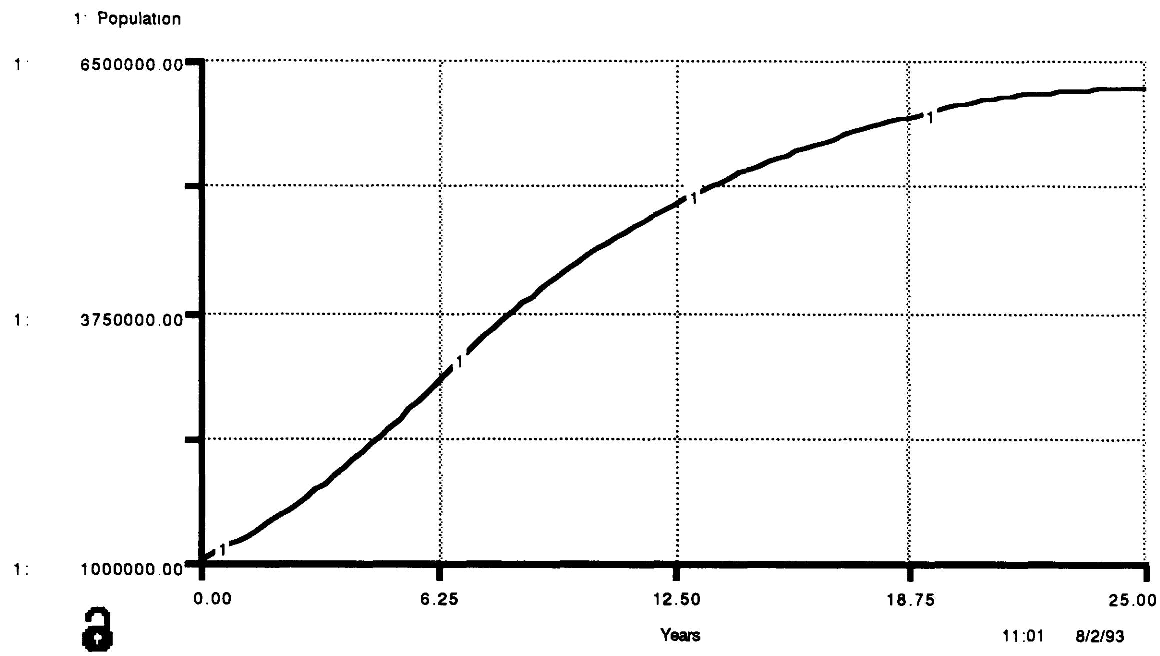

Figure 2.11: Population Growth
S-Shaped Growth

2.4 Model Validation

> "The validity [or significance] of a model should be judged by its suitability for a particular purpose." (Forrester 1961, p. 115)

Models simulate reality. When functioning of the world is questioned, a model may be developed so as to avoid the time, expense, danger, or efforts involved in building, testing, and modifying the world on a real time basis. Yet, when reality is only simulated will meaningful information be obtained? Because modelers, managers, and policy makers seek to guide future decisions with the knowledge gained from the model, validity presents an important issue. However, what constitutes validity remains somewhat controversial in the modeling community. Many have advocated "formal, objective, quantitative model validation procedures" to assure the scientific integrity of the modeling process and have criticized the system dynamicist for not employing such techniques. "System dynamicists have responded by stating that model validity is strongly tied to the nature and context of the problem, the purpose of the model, the background of the user, the background of the analyst, and other considerations. Accordingly, model validation is inherently a social, judgmental, qualitative process: models cannot be proved valid but can be judged to be so." (Barlas and Carpenter 1990, p. 148)

Less formal, qualitative validation procedures provide an attractive methodology for the system dynamics method because of the type of problems typically studied. Unlike physical and engineering models, system dynamics models are routinely built to simulate social systems where quantitative data is less available and less reliable than in the physical sciences. Consequently, modelers and decision makers must place greater reliance upon judgment as to the usefulness of the simulation. As Forrester comments, "the pertinent test is that of utility in improving ... practice[s]." Does the simulation and modeling process provide new insights into the workings of the system and enable better practices and policies to be developed and implemented? If so, then formal quantitative validation is of less concern. Accuracy and precision are less meaningful for most social models and could, in fact, be greatly misleading, as it would imply more precise knowledge than could be justified.

A model is after all a simulation of reality. Its validity lies not in whether the model is a perfect representation of reality but whether the representation can meet its intended purpose: to be useful in solving the proposed problem.

Chapter 3

3.0 Social Pressure, Safety Regulation Model

System dynamics presents a modeling tool well adapted for simulating the functions of complex social systems. Of importance to this thesis is how the social system relates to the nuclear power industry. A complex relationship exists between the public and a nuclear power plant; the performance and even the concept of the nuclear plant triggers concerns and, ultimately, actions within the public which are directed at altering the operations of that plant. Responses from the nuclear plant may beget more action from the public creating a loop of action and reaction with uncertain consequences. In creating the Social Pressure, Safety Regulation Model, or SPSRM, this thesis concentrates on the social system and its responses to nuclear performance. Hopefully, such a model will provide greater insight into the social functions regarding the nuclear industry. The following sections will first describe the model system and its boundaries, followed by a presentation of the causal relationships within that system, and finally the computer translation of the system and its causality.

3.1 System Boundaries

The Social Pressure, Safety Regulation Model concentrates upon the social aspects of the nuclear industry, or system. Consequently, the operations of the nuclear plant and activities of the nuclear industry are not within the model's boundaries. Although plant performance and industry activities are inputs, they are exogenous. No direct material or information flows or decision mechanisms exist within the SPSRM to alter industry or plant performance. (Although these paths exist, they are not within the scope of this thesis.)

The boundaries of the SPSRM include the public, or social, mechanisms for reacting to and altering nuclear performance. Social control of nuclear power exist primarily through the Federal Government which maintains control of nuclear regulation and oversight. The government body charged with these duties is the Nuclear Regulatory Commission (NRC) created from the Atomic Energy Commission in 1974 by the Energy Reorganization Act. The NRC creates and implements Federal Regulations and oversees the daily operation of all nuclear power facilities within the United States. Since Congress created the NRC specifying its authority, Congress remains a direct path for public oversight of the Commission and its activities. The SPSRM incorporates both Congress and the NRC as public controls within the boundaries of the social system.

Although the government is the primary public link for altering nuclear performance, it is not the only social structure actively influencing the nuclear arena. The public at large is concerned over nuclear safety. They perceive the risks associated with nuclear power and pressure government and industry to act responsibly. Such pressure generally does not come from individuals but rather from groups who form to further their social objectives concerning nuclear power. These interest groups provide a primary path for public action and are so represented within the SPSRM. The public at large also remains within SPSRM boundaries as a source for social perceptions and supporter of public action.

However, the social structure does not operate on action alone. Information transfer is paramount in the development of opinions which form the foundations for action. Here, the media plays an important role. The mass media, both print and electronic, keeps the public and government (especially Congress) informed on issues concerning nuclear power, not only reporting on nuclear performance but also on public actions and perceptions. The media is integral to information flow within the SPSRM.

Congress, the NRC, the Public, Interest Groups, and the Media form the core of the SPSRM. They define the social system which interacts with the nuclear industry to alter nuclear operations. Other inputs such as plant performance, industry lobbying and self regulation efforts, and private financial foundations affect the system but are exogenous; no feedback mechanism exist within the SPSRM to alter the levels of these inputs. (Such feedbacks may exist in reality and, consequently, will be incorporated in the overall model.)

3.2 Causal Relationships

What drives the public to be concerned or to seek change? What causes system behavior? The social system consist of various groups and organizations which act and react to information about the nuclear and social systems. Such information causes people to act, and such causality forms the basis of a model. The SPSRM emulates the cause and effect relationships observed among the various sectors within the nuclear, social system. Those causal structures direct the behavior of the model by specifying what information affects whom and how. The following sections shall describe the causal relationships constructed for each group within the SPSRM.

3.2.1 The Public

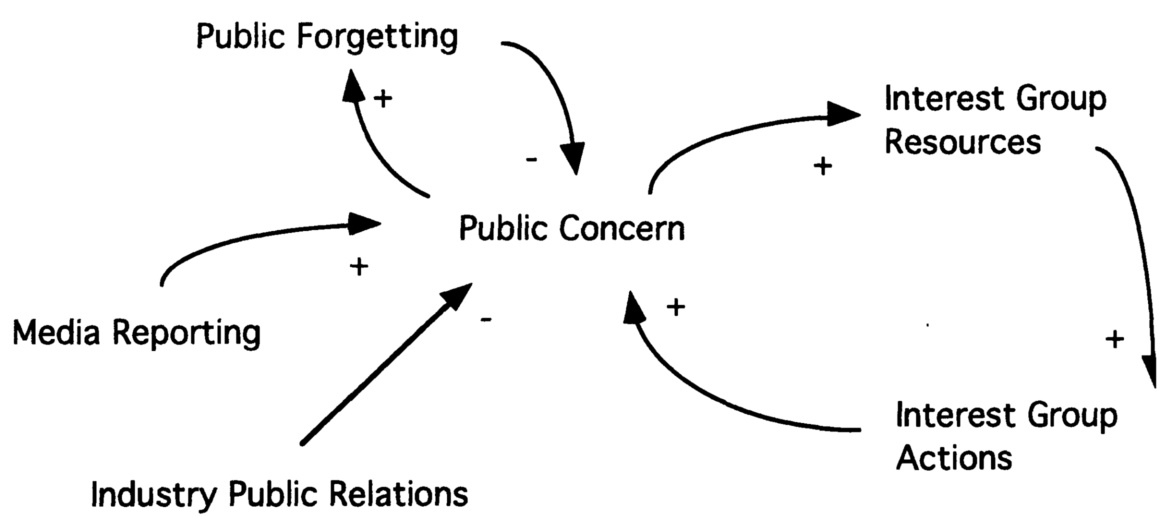

Figure 3.1: Causal Loop Diagram
Public Concern

The public at large expresses concern over nuclear safety. Nuclear power elicits certain fears and worries in the general public. Risk associated with nuclear fission, images surrounding "nuclear power" including associations with the bomb, fears of the unknowns of technology, and other motivators, all drive public opinions relating to nuclear power. These opinions create concern among some, and such concerns cause many to seek changes in nuclear operations.

Within the SPSRM, the media, interest groups, industry public relations, and time drive the level of public concern. The media dominates as a public source of information. However, the media cannot report everything; it selectively reports those items which it deems newsworthy. Regarding a nuclear power plant, newsworthy tends to center around unusual events --- especially those which may affect the health and safety of the public. Consequently, media attentions generally increases nuclear concerns. (No criticism intended; it is simply an observation of what people generally consider as important.)

Because the level of public concern greatly affects an interest group's level of support, such groups actively seek to raise public concern. Mailings, protest, etc. are various means for directly converting people to a group's cause. Like interest groups, the utility maintains a vested interest in public support. Consequently, they too actively seek to alter public concern, trying through public relations and information efforts to lower concern and build support for continued nuclear operations. Time is the final driver. People forget mailings and events; consequently, with time a natural decay of concern occurs.

3.2.2 Interest Groups

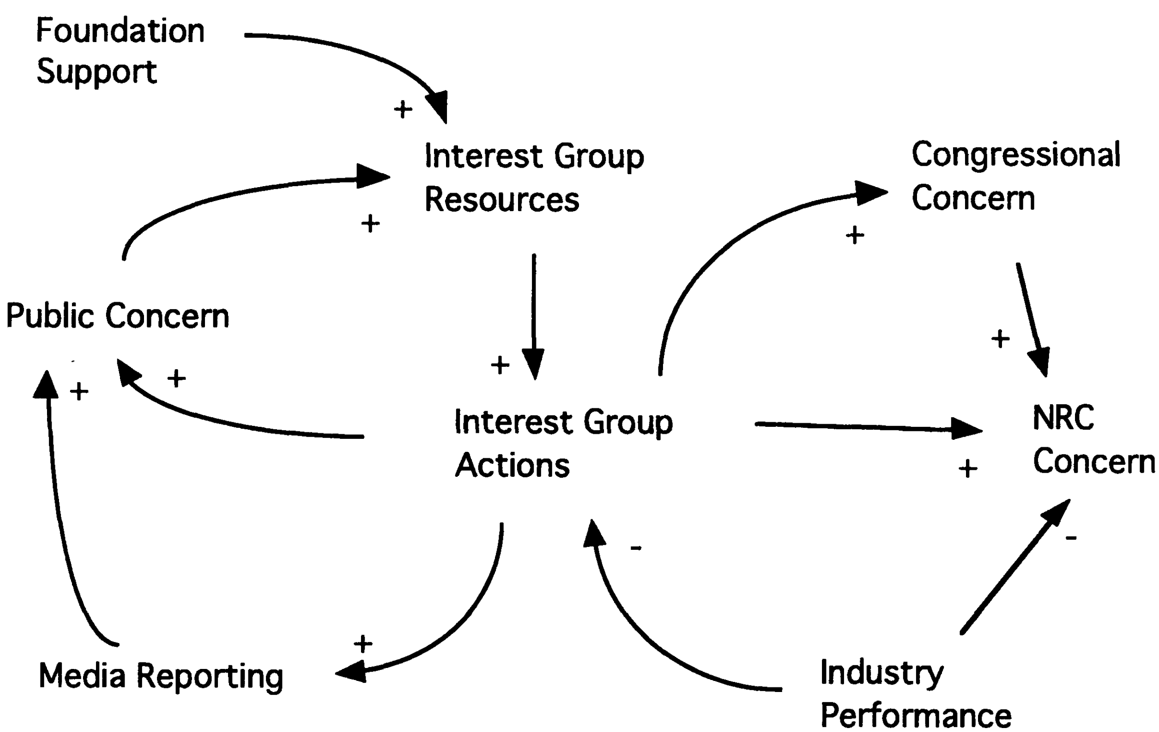

Figure 3.2: Causal Loop Diagram
Interest Groups

Groups develop to further a variety of interests. The nuclear industry is not unique in that aspect. Both existing and newly developed organizations express desires to alter the nuclear utility. Some seek to eliminate nuclear reactors, others simply to improve performance and safety. As stated before, public action occurs through interest groups. Concern supports the interest groups, but it is the groups which influence the government and utility.

Financial resources enable such groups to function. It is the primary driver of group actions. Two sources of support exist: private foundations and the public. Public support is directly coupled to concern. As concern rises, financial donations to support group actions increase. Conversely, such support decreases if concern lessens. Although foundation support may in some manor be tied to public concern, here it is considered independent and constant.

Although the financial resources limit group actions, events within the nuclear industry directly affect the rate, efficiency, and timing of such expenditures. An accident at any nuclear plant elicits an immediate response from interest groups to highlight the potential consequences of nuclear reactor operation. Events increase the rate of spending of available moneys and produce efforts to spend more efficiently.

3.2.3 Congress

The legal mandate for government involvement in the nuclear industry originates in the U.S. Congress. It writes the laws which create both regulations and regulators. Consequently, Congress exhibits much influence upon the industry both directly in the laws passed and indirectly through the commentary of individual lawmakers.

In the SPSRM, the legal framework is a given. No structure for creating laws is included. However, Congress does alter NRC actions. As Congressional Concern increases, lawmakers place additional pressure upon the NRC to assure nuclear safety: see Figure 3.3.

Figure 3.3 shows the causal relationships affecting Congress. The public, through interest groups; the nuclear industry; the media; the NRC; and time all contribute to Congressional Concern. Interest groups and the industry both lobby Congress, trying to persuade lawmakers toward their views: interest groups trying to heighten concern while the industry tries to lessen concern and build confidence in nuclear safety. The media helps keep Congress informed of happenings within the industry and the public sentiment. As with the public, media reports tends to increase Congressional Concern. Somewhat unique to the government, including Congress, is the NRC's impact at alleviating concern. The NRC's mandate is to assure nuclear safety and actions taken towards those ends help alleviate Congressional worries over safety. Again like the public, Congress forgets; nuclear concern diminishes as other issues surface and nuclear issues fade.

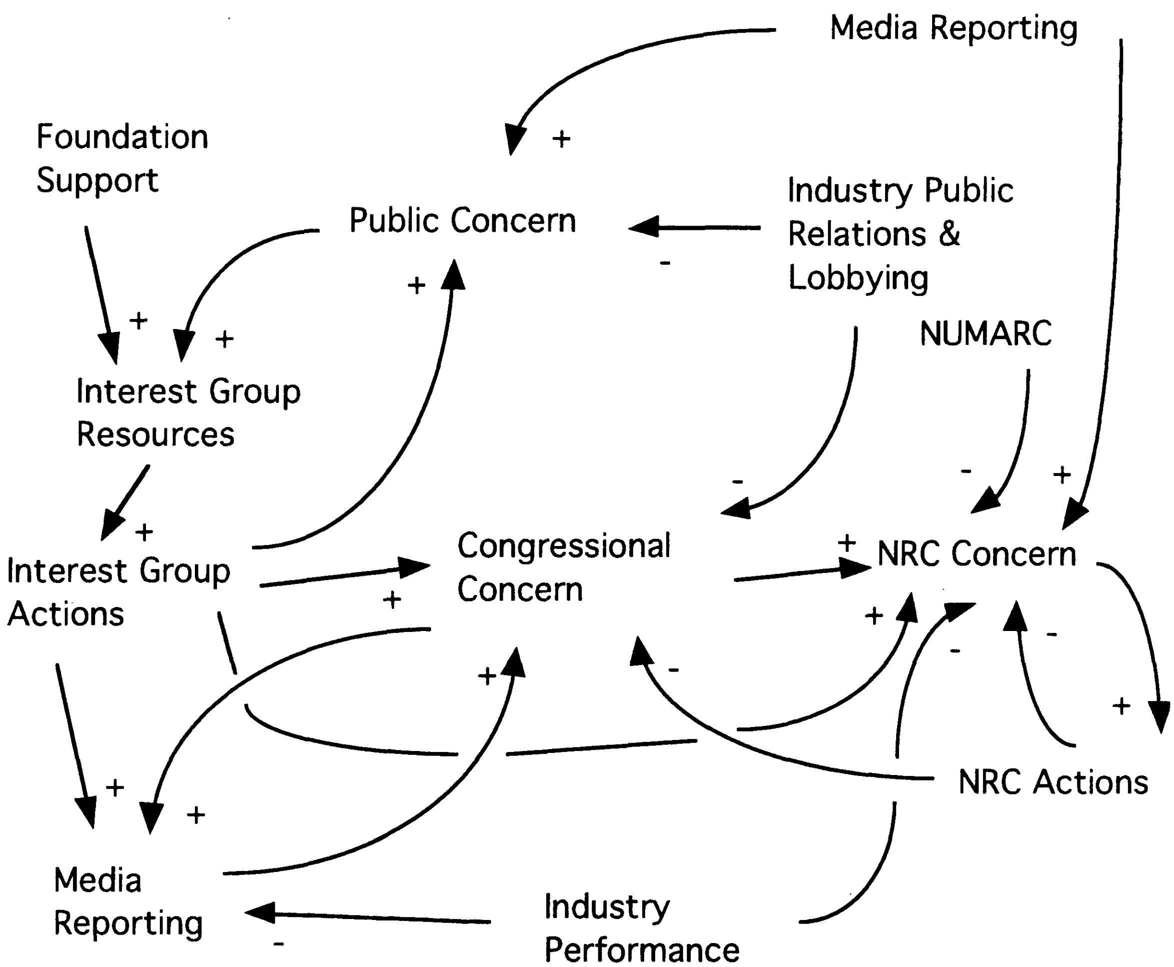

Figure 3.3: Causal Loop Diagram
Social Pressure / Safety Regulation

3.2.4 Nuclear Regulatory Commission

Since government oversight falls to the NRC, all efforts at guiding government nuclear policy ultimately target this agency. Efforts to influence and inform the agency plus its own efforts at oversight all impact NRC concern for nuclear safety. It is this concern which drives the agency's actions to assure safety.

Because the NRC seeks safety in nuclear operations, concern is directly coupled to plant performance. Not only do accidents and major events cause concern to rise, but any information which indicates a higher probability of such an occurrence also increases NRC concern. Three sources inform the NRC of industry performance: normal utility to NRC communications, License Event Reports, and utility informants. On a routine basis, nuclear plants supply reports and operating updates to the NRC. Such information may heighten or lesson concern depending on what level of utility performance is indicated. If a deviation from technical specifications occurs, utilities must file a License Event Report (as mandated by 10 CFR 50) with the NRC; such reports increase concern because they indicate a deviation from normal operation. Finally, personnel within a nuclear facility may contact the NRC to inform them of potential hazards at the plant. Such information increases concern.

NRC policies and perceptions of such policies affect the interest of various groups associated with the nuclear industry. Because of this, several groups actively seek to alter NRC policy by presenting differing perspectives on NRC actions, utility performance, and operating consequences. If a group succeeds, such presentations may alter NRC concern and guide NRC action. In the SPSRM, such groups are either 1) interest groups which campaign to raise NRC concern and government oversight or 2) industry associations -- represented by the Nuclear Management and Resource Council (NUMARC) -- which seek to lesson NRC concern by demonstrating the industries commitment to safe operation.

Congress also seeks to guide NRC policy and actions, especially when Congressional concern over nuclear issues is heightened: such actions increase NRC concern. Finally, the media affects NRC concern. Although not actively seeking changes in the NRC, media articles reflect the public attitudes over nuclear power, attracting NRC attention and tending to increase concern since most articles bend toward the negative on nuclear power.

The NRC's own actions also alleviates concern. By acting, the NRC counters the causes which originally drove its concern.

3.2.5 Media

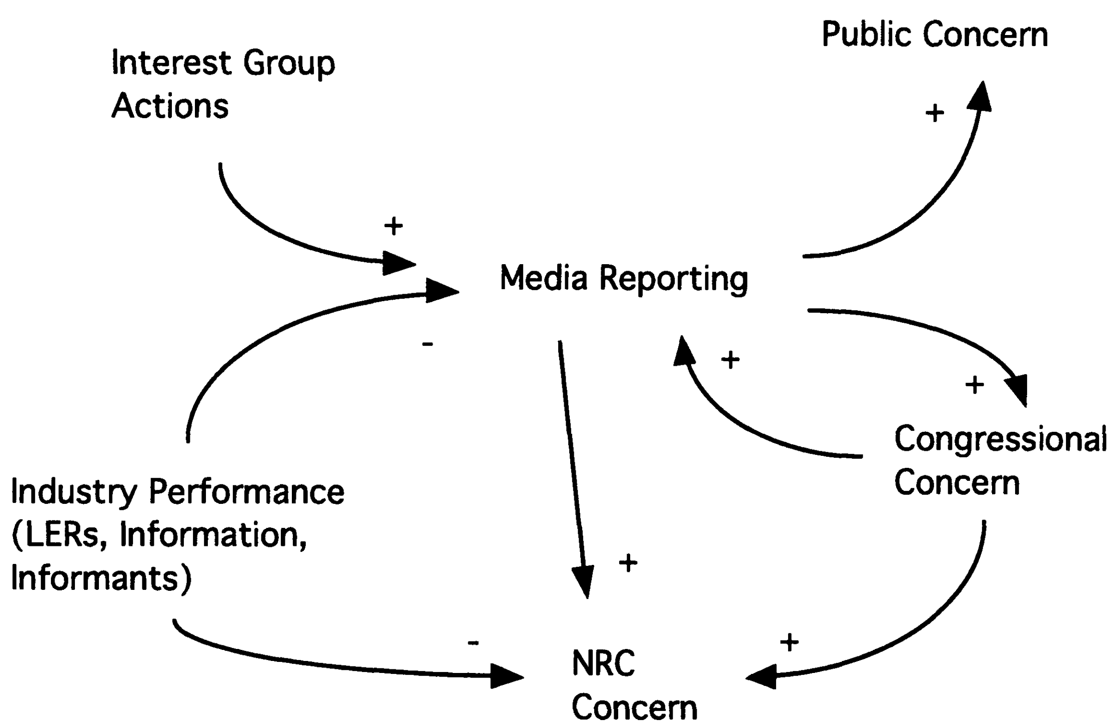

Figure 3.4: Causal Loop Diagram
Media Reporting

The media represents the prime source of information for many, especially the public and Congress. (The NRC and interest groups maintain direct sources of industry information.) The media seeks information from multiple sources and reports such information when of sufficient quality to warrant news. Interest group actions, industry events, utility reports, plant informants, and Congressional releases all provide information to the media. Information varies on news worthiness, and only such information considered of high quality and news worthiness is actually reported -- independent of the slant of such information but recognizing that harm or potential harm qualifies more often as news as opposed to normal conditions.

3.3 Computer Representation

To simulate the SPSRM, the system along with its causality must be structured in the language of mathematics. This allows for the integration of the system over time to study the dynamics of system behavior. It also enables the modeler and the critic to view the system under the precise rule of mathematical logic: the mathematics remove the ambiguities and assumptions which sometimes remain clouded in verbal descriptions. Additionally, structuring the model as such provides the ability to utilize digital computers to quicken and ease the simulation process. The SPSRM has been written using Stella II, a system dynamics software package for Macintosh Computers.

To provide a logical format, the SPSRM has been divided into seven sectors. Five follow the subdivisions in the previous causal relations section: Public, Interest Groups, Congress, NRC, and the Media. Exogenous inputs are included in another sector, and a final sector covers miscellaneous calculations. A graphical, written, and mathematical description of each sector follows, including a breakdown of the modeling structure: stocks (**S**), converters (**O**), and constants (**C**).

3.3.1 Public Sector

The public sector simulates the general public. It expresses public concern and the public support such concern implies. As stated previously, concern represents the fears and worries the general public expresses over nuclear power operations. To represent this, the SPSRM divides the U.S. population into two groups: those concerned about nuclear power and those unconcerned. Those who seek greater oversight and/or elimination of nuclear power reside in the concerned population while those who support or are neutral on nuclear power reside in the unconcerned population. It is not to say that the unconcerned population have no worries, but they are generally supportive and not actively against nuclear power.

From the causal structure, concerned individuals support interest group activities. Such support appears as monetary donations to finance interest group activities, and a portion of the concerned public will express that concern through donations.

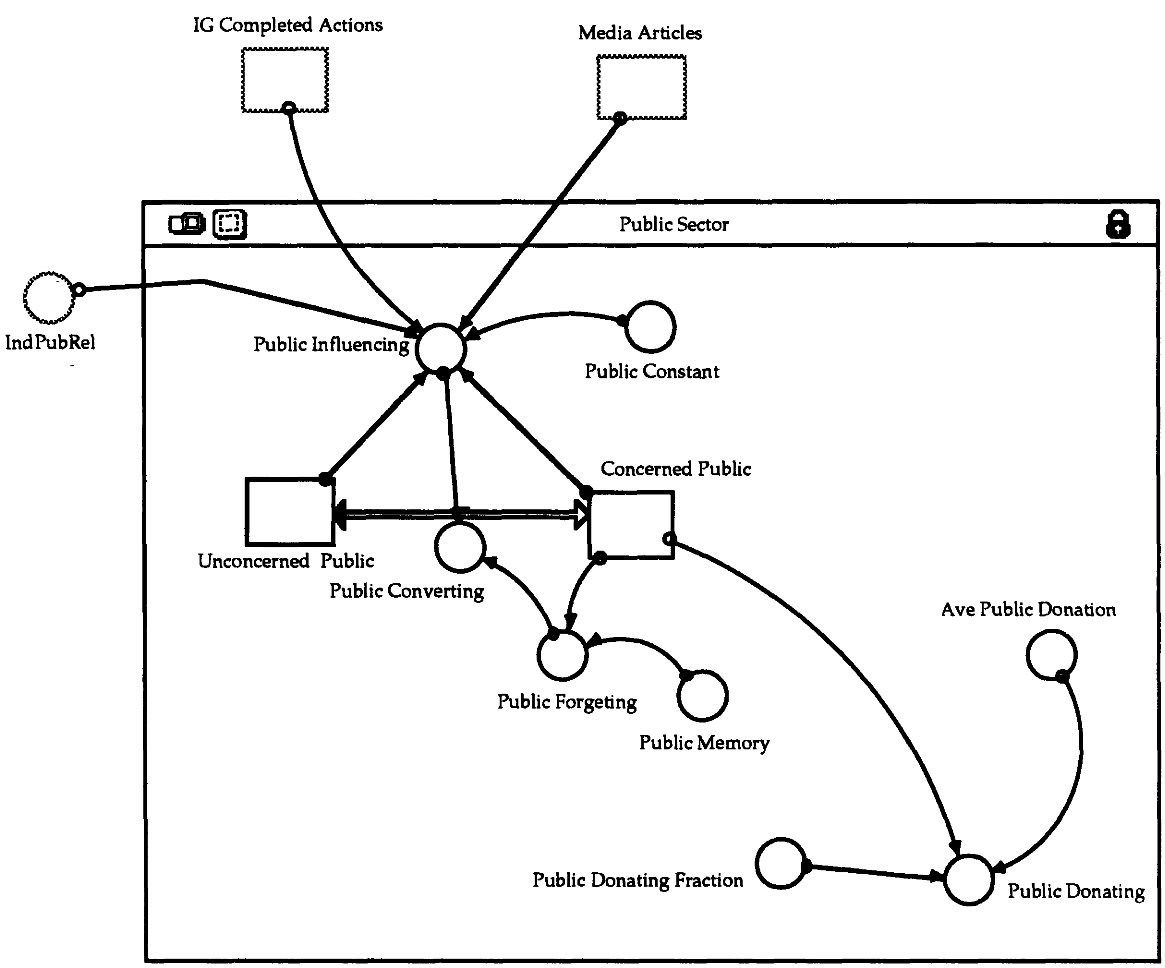

Figure 3.5: Stella Diagram
Public Sector

3.3.1.1 Stocks and Flows

Stock	Units	Inflow	Outflow	Units
Concerned Public	People	Public Converting	Public Converting	People / Month
Unconcerned Public	People	Public Converting	Public Converting	People / Month

The SPSRM represents the two population groups as levels: the concerned public and unconcerned public. People may flow from one group to the other -- concerned or unconcerned -- as determined by Public Converting, a rate calculation dependent upon the passage of time and the external forces which influence each population group. To start the simulation, an initial state of ten percent concerned and ninety percent unconcerned is given.

3.3.1.1.1 Stock and Flow Equations

S Concerned Public(t) = Concerned Public(t - dt) + (Public Converting) * dt

Initial Conditions: Concerned Public = .10 * Population Size

Inflows:

1. Public Converting = Public Influencing - Public Forgetting

S Unconcerned Public(t) = Unconcerned Public(t - dt) - (Public Converting) * dt

Initial Conditions: Unconcerned Public = .90 * Population Size

Outflows:

1. Public Converting = Public Influencing - Public Forgetting

3.3.1.2 Converters

Converter	Units	Inputs
Public Influencing	People / Month	1. Media Articles 2. IG Completed Action 3. Ind Pub Rel 4. Concerned Public 5. Unconcerned Public
Public Forgetting	People / Month	1. Concerned Public 2. Public Memory
Public Donating	Dollars / Month	1. Concerned Public 2. Ave Public Donation 3. Pub Donating Fract

Two conversion calculations, Public Influencing and Public Forgetting, combine to form the conversion rate (public converting) between concerned and unconcerned individuals. Public Influencing combines the effects of Media Articles, Interest Group Actions, and Nuclear Industry Public Relations in converting individuals between the two populations. Public Forgetting accounts for the dissipation of concern through the passage of time: memory of the incidents and information which converted individuals fades with time, after which some shall no longer remained concerned.

Public Donations, the third converter, calculates the public's financial support of the interest group activities. The only action and primary influence of the public sector, Public Donating takes the Average Public Donation and the Public Donating Fraction to calculate the interest group support from the concerned population.

3.3.1.2.1 Converter Equations

- Public Donating = Concerned Public * Ave Public Donation * Public Donating Fraction

- Public Forgetting = Concerned Public / Public Memory

O Public Influencing = ((IG Completed Actions * Unconcerned Public) + (Media Articles * Unconcerned Public) - (IndPubRel * Concerned Public)) * Public Constant

3.3.1.3 Constants

Constants	Units
Public Memory	Months
Average Public Donation	Dollars / Month
Public Donating Fraction	People Donating / Concerned People
Public Constant	% Converted / Action

Public Memory supplies the average time, in months, required for converting efforts and information to fade from individual memory. Average Public Donation gives the average donation, in dollars per month, received by interest groups from the Concerned Public. The Public Donating Fraction provides the fraction of the Concerned Public who donate money to interest groups, given that all those concerned may not donate. And the Public Constant specifies the percent of people converted by each action which influences people to convert.

3.3.1.3.1 Constant Values

C Ave Public Donation = 1
C Public Donating Fraction = .0025
C Public Memory = 12
C Public Constant = 1/1000

3.3.1.4 External Variables

External Variable	Source Sector
I G Completed Actions	Interest Group
Media Articles	Media
Industry Public Relations	Exogenous

Interest group actions, media articles, and industry public relations all combine to influence people to convert from one group to the other -- concerned to unconcerned and vice versa.

3.3.2 Interest Group Sector

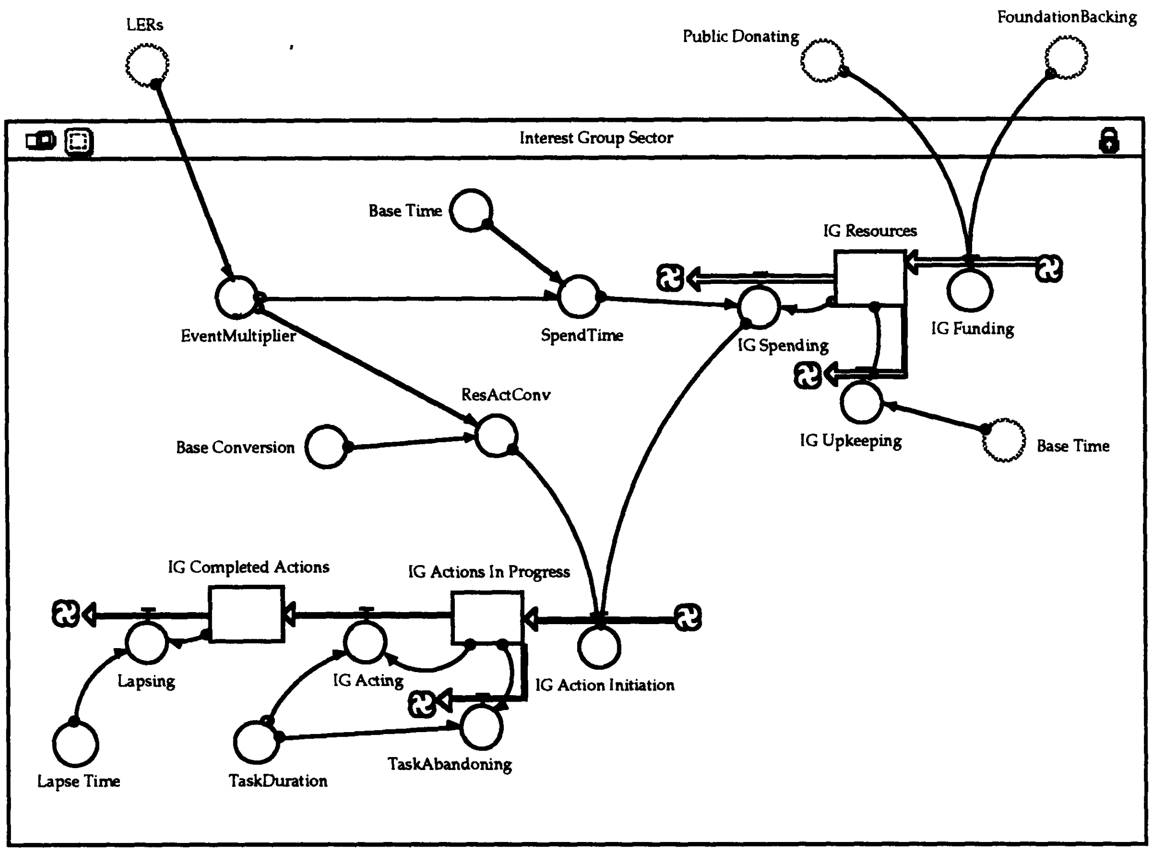

Figure 3.6: Stella Diagram
Interest Group Sector

The Interest Group Sector represents public action. It simulates interest group activities, the primary function of which is to influence the opinions and actions of others. Groups rather than individuals provide the path for public participation in the nuclear industry. Within this model, no other path exist for the public to alter the actions of the government and utility.

Although the sector models interest group actions, it does not track individual group action or development. Interest group resources and actions represent the collective efforts of all interest groups.

3.3.2.1 Stocks and Flows

Stocks	Units	Inflow	Outflow	Units
IG Resources	Dollars	IG Funding	IG Spending	Dollars / Month
IG Actions in Progress	Actions	IG Action Initiation	1. IG Acting 2. Task Abandoning	Actions / Month
IG Completed Actions	Actions	IG Acting	Lapsing	Actions / Month

The causality section distinguishes interest group resources as a driver of interest group actions, which then influence others. Here stocks represent both resources and actions: resources being covered with a single stock while actions are disaggregated into two.

Donated dollars flow into IG Resources where they are held, as in a bank account, until spent for group actions or group maintenance, i.e. overhead. As the reservoir of available funds, IG Resources financially bounds the activities of the interest group sector. The activities themselves are tracked through the levels, IG Actions in Progress and IG Completed Actions. Groups spend resources to initiate actions which are accounted for within Actions in Progress until such actions are completed or discarded. To influence others, actions must be completed and reside within the level IG Completed Actions. Here actions remain until their influence has subsided, a duration set by Lapse Time.

The several levels within this structure help simulate the delays and drains viewed in the world of group action and behavior. Influence is not immediate with donations nor do all resources ultimately affect designated targets: public, Congress, NRC.

3.3.2.1.1 Stock and Flow Equations

S IG Resources(t) = IG Resources(t - dt) + (IG Funding - IG Upkeeping - IG Spending) * dt

Initial Conditions: IG Resources = FoundationBacking + Public Donating

Inflows:

1. IG Funding = Public Donating + FoundationBacking

Outflows:

1. IG Spending = IG Resources / Spend Time
2. IG Upkeeping = IG Resources / (3*Base Time)

S IG Actions In Progress(t) = IG Actions In Progress(t - dt) + (IG Action Initiation - IG Acting - TaskAbandoning) * dt

Initial Conditions: IG Actions In Progress = 50

Inflows:

1. IG Action Initiation = IG Spending * ResActConv

Outflows:

1. IG Acting = (IG Actions In Progress / TaskDuration)
2. TaskAbandoning = IG Actions In Progress / (4 * TaskDuration)

S IG Completed Actions(t) = IG Completed Actions(t - dt) + (IG Acting - Lapsing) * dt

Initial Conditions: IG Completed Actions = 10

Inflows:

1. IG Acting = (IG Actions In Progress / TaskDuration)

Outflows:

1. Lapsing = IG Complete Actions / Lapse Time

3.3.2.2 Converters

Converter	Units	Inputs
Event Multiplier	Dimensionless	LERs
Spend Time	Months	1. Base Time 2. Event Multiplier
Resource-Action Conversion	Dollars / Action	1. Base Conversion 2. Event Multiplier

Converters within the interest group sector combine to calculate the rate at which dollars are spent to initiate group actions and the impact per dollar that the spending may produce. Industry performance, here in terms of size and quantity of events, affects the rate and conversion of dollars to actions. LERs drive the Event Multiplier, which alters both the base rate of spending, calculated in Spend Time, and the base conversion of dollars to actions, calculated in Resource-Action Conversion. This structure simulates a groups efforts to utilize an event to highlight their concerns: an accident re-enforces peoples concern over nuclear power and the model accelerates interest group activities to publicize such events.

3.3.2.2.1 Converter Equations

- EventMultiplier = GRAPH(LERs)
  Points:
  (0.00, 1.00), (10.0, 1.00), (20.0, 1.10), (30.0, 1.25), (40.0, 1.40), (50.0, 1.60), (60.0, 2.00), (70.0, 2.60), (80.0, 3.45), (90.0, 5.30), (100, 10.0)

- ResActConv = Base Conversion * EventMultiplier

- SendTime = Base Time / EventMultiplier

3.3.2.3 Constants

Constants	Units
Base Time	Months
Base Conversion	Dollars / Action
Task Duration	Months
Lapse Time	Months

Constants control flow rates to and from the various levels. Base Time supplies the base rate of resource spending; Base Conversion relates dollars to actions; Task Duration gives the average project length; and Lapse Time specifies the average time for which a completed action shall continue to influence other sectors.

3.3.2.3.1 Constant Values

C Base Conversion = .0001
C Base Time = 6
C Lapse Time = 1
C TaskDuration = 4

3.3.2.4 External Variables

External Variable	Source Sector
Public Donating	Public
Foundation Backing	Exogenous
LERs	Exogenous

Money and industry performance drive interest group behavior. Money flows from private foundations and the public to support interest group activities, which are a response to the group's concern over nuclear power. Because accidents and other major events highlight group concerns, industry performance, here represented by LERs, significantly accelerates group actions.

3.3.3 Congressional Sector

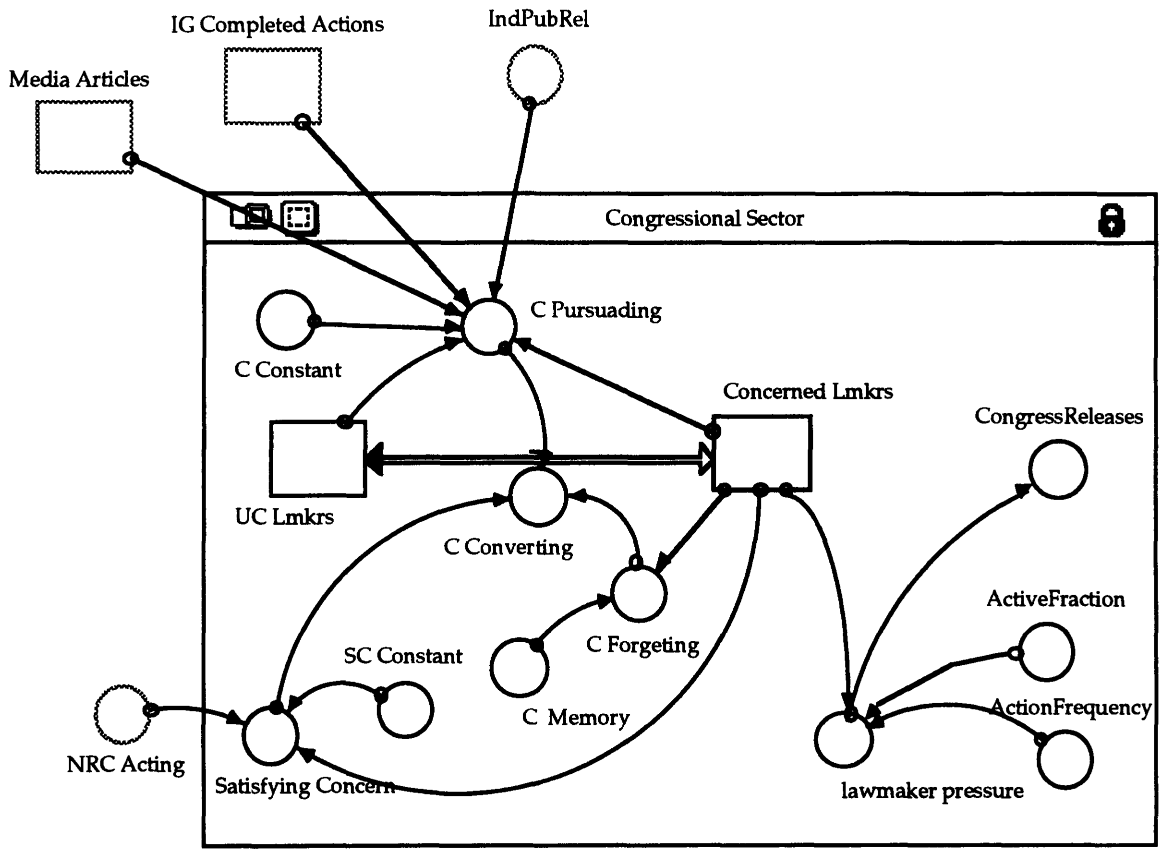

Figure 3.7: Stella Diagram
Congressional Sector

Congress represents the elected government and is consequently subject to social persuasion. Because Congress also oversees the NRC, it is a conduit for public pressure to influence nuclear regulatory policies. Social and industry persuasion affects Congressional concern, which is treated much the same as public concern: i.e. concerned and unconcerned lawmakers. Concerned implies that lawmakers are worried about public health and safety in regards to nuclear power. It also implies that nuclear power is of great enough interest to warrant a lawmakers time and efforts. Like the concerned public, concerned lawmakers influence others -- here the NRC through contact and pressure to alter regulatory practices.

3.3.3.1 Stocks and Flows

Stock	Unit	Inflow	Outflow	Units
Unconcerned Congress	Lawmakers	Congress Converting	Congress Converting	Lawmakers / Month
Concerned Congress	Lawmakers	Congress Converting	Congress Converting	Lawmakers / Month

Like the general public, two levels track concerned and unconcerned lawmakers, who may be converted from one group to the other by external influences and time.

3.3.3.1.1 Stock and Flow Equations

S Concerned Lmkrs(t) = Concerned Lmkrs(t - dt) + (C Converting) * dt
Initial Conditions: Concerned Lmkrs = .1 * Lawmakers
Inflows:
1. C Converting = C Persuading - C Forgetting - NRC Satisfying

S Unconcerned Lmkrs(t) = Unconcerned Lmkrs(t - dt) - (C Converting) * dt
Initial Conditions: Congress = 0.9 * Lawmakers
Outflows:
1. C Converting = C Persuading - C Forgetting - NRC Satisfying

3.3.3.2 Converters

Converter	Units	Inputs
C Persuading	Lawmakers / Month	1. Ind Pub Relations 2. IG Completed Actions 3. Media Articles
C Forgetting	Lawmakers / Month	1. Concerned Lawmakers 2. C Memory
NRC Satisfying	Lawmakers / Month	1. Concerned Lmkrs 2. NRC Action
Lawmaker Pressure	Initiatives / Month	1. Concerned Lmkrs 2. Active Fraction 3. Action Frequency
Congressional Releases	Releases / Month	1. Lawmaker Pressure

Converters calculate the influences upon lawmakers and the influences exerted by lawmakers. Persuading, Forgetting, and NRC Satisfying all affect the conversion of lawmakers between concerned and unconcerned groups. Persuading adds the external effects of the media, interest groups, and the industry. Forgetting calculates the concerns which dissipate with the passage of time. NRC Satisfying calculates the impact of NRC actions upon concerned lawmakers: regulatory action alleviates some lawmaker concerns.

Lawmaker Pressure and Congressional Releases both calculate Congressional impacts. Pressure represents the initiatives of Congress to alter NRC behavior and is a function of concerned lawmakers, active fraction, and action frequency. Congressional Releases represents the quantity of Congressional correspondence with the media and is simply a linear function of concerned lawmakers.

3.3.3.2.1 Converter Equations

O C Forgetting = Concerned Lmkrs / C Memory

O C Persuading = (((IG Completed Actions + Media Articles) * Unconcerned Lmkrs) - (IndPubRel * Concerned Lmkrs)) * C Constant

O NRC Satisfying = (NRC Acting * Concerned Lmkrs) * NRC Affect

O lmkr pressure = Concerned Lmkrs * ActiveFraction * ActionFrequency

O CongressReleases = .1 * lmkr pressure

3.3.3.3 Constants

Constants	Units
Congressional Memory	Months
Active Fraction	Active Lmkrs / Concerned Lmkrs
Action Frequency	Initiatives / Active Lmkrs / Month
Congressional Constant	% Converted / Action
NRC Affect	% Converted / NRC Action

Congressional Memory supplies the average time, in months, for concerns to dissipate simply as a function of time. Both Active Fraction and Action Frequency affect lawmaker pressure, specifying the fraction of concerned lawmakers who actually take initiatives to influence the NRC and the average frequency of such initiatives. Both the Congressional Constant and the NRC Affect relate the ability of external influences and NRC actions to convert lawmakers from concerned or unconcerned groups.

3.3.3.3.1 Constant Values

C ActionFrequency = .1

C ActiveFraction = .1

C C Memory = 12

C C Constant = 1/100

C NRC Affect = 1/10

3.3.3.4 External Variables

External Variables	Source Sector
Media Articles	Media
IG Completed Actions	Interest Group
Ind Pub Relations	Exogenous
NRC Acting	NRC

Because Congress is a path for influencing government nuclear policies, it is affected by several groups. The public through interest groups and the media, the industry, and the NRC all seek influence over Congressional attitudes over nuclear safety.

3.3.4 Nuclear Regulatory Commission Sector

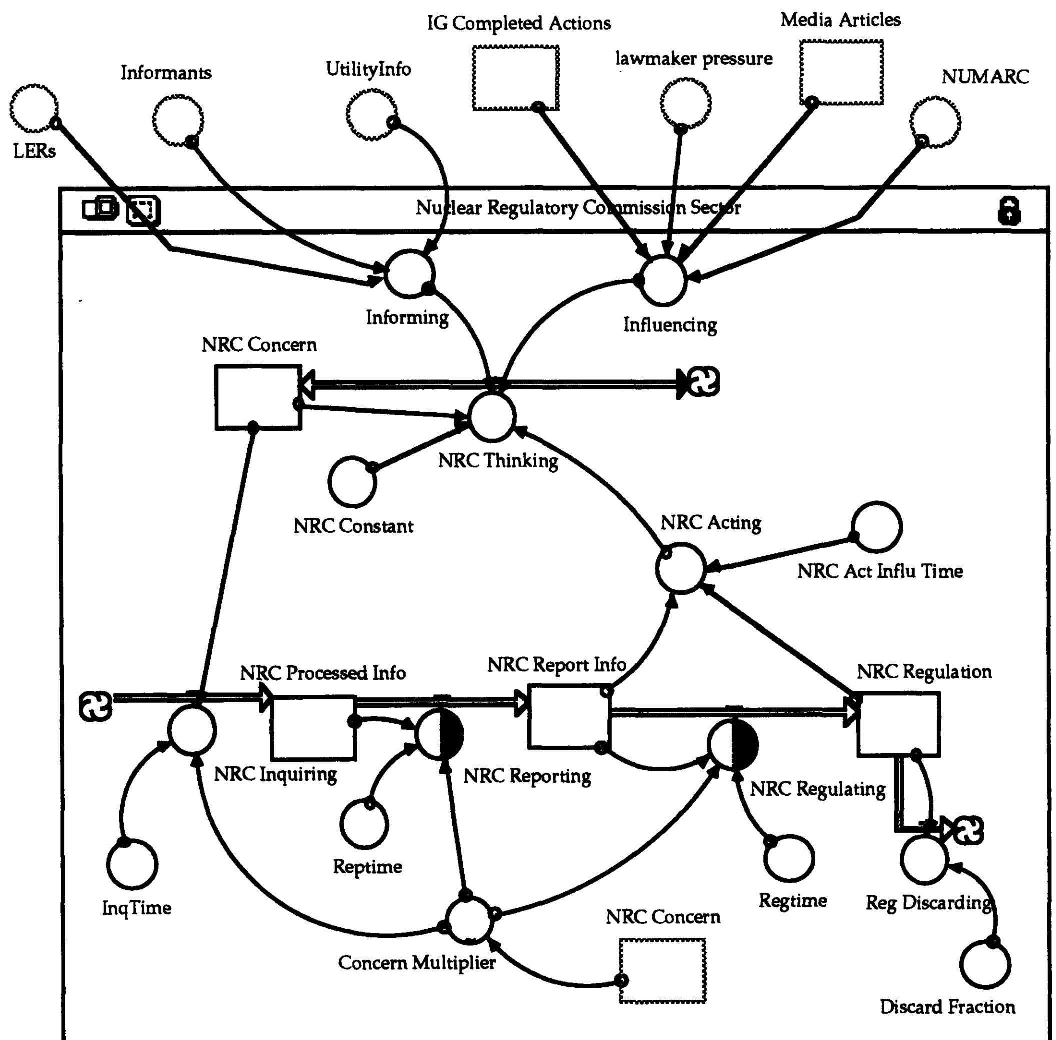

Figure 3.8: Stella Diagram
NRC Sector

The NRC implements government policy concerning nuclear safety. Its objective is to assure public safety in regards to nuclear power operations, and to achieve this it actively regulates the industry. NRC actions including regulation vary with the agency's level of concern over nuclear safety. As stated previously, such concern is primarily driven by industry performance, but also affected by the media and groups which seek to alter agency policies. Although NRC actions directly affect plant operations and performance, such impacts are external to the SPSRM and consequently not simulated here.

3.3.4.1 Stocks and Flows

Stock	Units	Inflows	Outflows	Units
NRC Concern	Concern	NRC Thinking	NRC Thinking	Concerns / Action
NRC Processed Info	Pages	NRC Inquiring	NRC Reporting	Pages / Month
NRC Report Info	Pages	NRC Reporting	NRC Regulating	Pages / Month
NRC Regulation	Pages	NRC Regulating	Regulation Discarding	Pages / Month

Two types of stocks are present in the NRC sector: concern and action. Concern is the driver of all NRC action. It is an artificial scale from zero to one hundred where zero concern leads to no actions -- no new regulations -- and one hundred concerns prompts the shutdown of all U.S. nuclear power plants. The level of concern is affected by industry performance, social and political pressure, industry safety efforts, and the NRC's own actions. Concern drives the rate of inquiring -- investigating potential safety items -- which begins a series of NRC actions that may eventually lead to regulatory changes. Inquiring accumulates processed information, data from both industry records and investigator efforts covering the point of inquiry. A portion of this information shall be reported to the industry in the form of information notices, maintenance reports, etc. Such reports accumulate in the Reported Information Level where with time they may lead to regulation development. The Regulation level hold pages of regulation until such time that it is discarded (currently that is never). All action levels are in pages of information, reports, or regulations, and set conversions relate pages of one to pages of the other.

3.3.4.1.1 Stock and Flow Equations

S NRC Concern(t) = NRC Concern(t - dt) + (NRC Thinking) * dt
Initial Conditions: NRC Concern = 3
Inflows:
1. NRC Thinking = ((Informing + Influencing - NRC Acting) * NRC Concern) / (NRC Constant)

S NRC Processed Info(t) = NRC Processed Info(t - dt) + (NRC Inquiring - NRC Reporting) * dt
Initial Conditions: NRC Processed Info = 5
Inflows:
1. NRC Inquiring = (NRC Concern / InqTime) * Concern Multiplier
Outflows:
1. NRC Reporting(o) = (NRC Processed Info / Reptime) * Concern Multiplier

S NRC Report Info(t) = NRC Report Info(t - dt) + (NRC Reporting - NRC Regulating) * dt
Initial Conditions: NRC Report Info = 5
Inflows:
1. NRC Reporting(i) = NRC Reporting(o) * Conversion multiplier
Conversion multiplier = 0.5
Outflows:
1. NRC Regulating(o) = (NRC Report Info / RegTime) * Concern Multiplier

S NRC Regulation(t) = NRC Regulation(t - dt) + (NRC Regulating - Reg Discarding) * dt

Initial Conditions: NRC Regulation = 10

Inflows:

1. NRC Regulating(i) = NRC Regulating(o) * Conversion multiplier

Conversion multiplier = 0.1

Outflows:

1. Reg Discarding = Discard Fraction * NRC Regulation

3.3.4.2 Converters

Converter	Units	Inputs
Informing	Concerns / Month	1. LERs 2. Utility Info 3. Informants
Influencing	Concerns / Month	1. Lmkrs Pressure 2. IG Completed Acts. 3. Media Articles 4. NUMARC
NRC Acting	Concerns / Month	1. NRC Regulation 2. NRC Report Info 3. NRC Act Influ Time
Concern Multiplier	Unitless	1. NRC Concern

Informing, Influencing, and Acting all calculate the various impacts on NRC Thinking, the rate of changing concern. Informing covers the direct sources of information on plant performance: i.e. License Event Reports, Utility Information, and utility Informants. Persuasion falls within the influencing calculation. Congress, interest groups, NUMARC activities, and the media directly and indirectly persuade NRC thinking. Since the NRC inquires, reports, and regulates in response to concerns, actions designed to correct those concerns -- the reports and regulations -- also alleviate that concern over time.

While the above calculations affect the level of concern, the Concern Multiplier alters the impact of NRC Concern. A general rise in concern not only increases the agency's inquiring but also accelerates the development of reports and regulations which are already in the pipeline. The multiplier correlates concern with the inquiring, reporting, and regulating rates.

3.3.4.2.1 Converter Equations

O Influencing = ((IG Completed Actions * .25) + (Media Articles * .25) + (lmkr pressure) - (NUMARC)) / 1

O Informing = Informants + LERs - UtilityInfo

O NRC_Acting = ((NRC Report Info * .1) + (NRC Regulation)) / NRC Act Influ Time

O Concern Multiplier = GRAPH(NRC Concern)
Points:
(0.00, 0.1), (10.0, 3.00), (20.0, 5.45), (30.0, 7.20), (40.0, 8.20), (50.0, 9.00), (60.0, 9.40), (70.0, 9.65), (80.0, 9.80), (90.0, 9.95), (100, 10.0)

3.3.4.3 Constants

Constants	Units
Inquiry Time	Months
Report Time	Months
Regulation Time	Months
Discard Time	Months
NRC Action Influence Time	Months
NRC Constant	% Concerns / Action

Constants within this sector provide the various time variables for the different rate equations. Inquiry time provides the average number of months required to collect processed information. The average time to take processed information and release it in a report format is given by Report Time, while the average time for transforming the issues presented by reports into regulation is Regulation Time. Discard Time is the average span which regulations remain on the books: currently considered to be infinite.

Reports and regulation also alleviate the concerns which prompted their development. The average time for this process is given by the NRC Action Influence Time.

3.3.4.3.1 Constant Variables

C Discard Fraction = 0
C InqTime = 6
C NRC Act Influ Time = 2
C NRC Constant = 100
C Regtime = 24
C Reptime = 6

3.3.4.4 Exogenous Variables

External Variables	Source Sector
LERs	Exogenous
Utility Information	Exogenous
Informants	Exogenous
Lawmaker Pressure	Congressional
IG Completed Actions	Interest Group
Media Articles	Media
NUMARC	Exogenous

Since the NRC implements government nuclear policies, all efforts and activities which might influence that policy affect the NRC in some manor. Efforts include any groups seeking influence over nuclear policy, and activities include the day to day experience of the industry.

3.3.5 Media

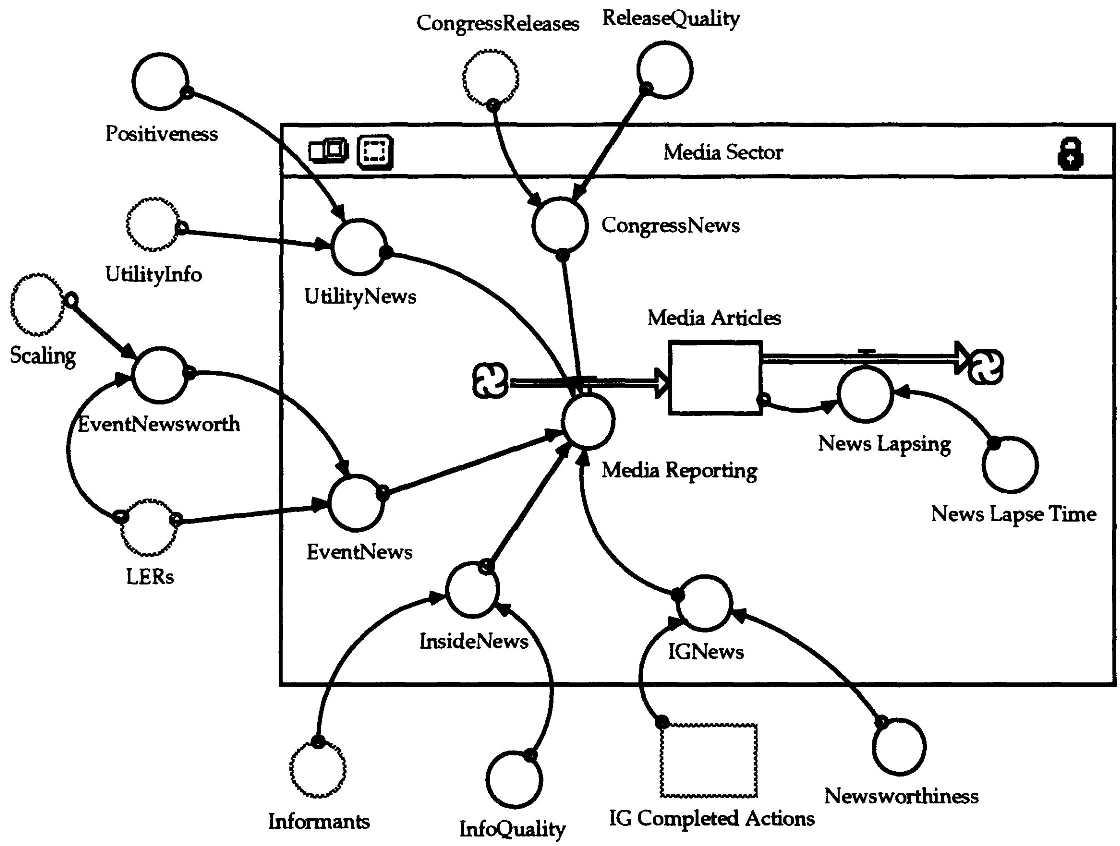

Figure 3.9: Stella Diagram
Media Sector

The media transmits information. Although the NRC and interest groups maintain their own information channels, both the public and Congress receive most nuclear information from the media, making it significant player in the development of public and Congressional opinion. As stated earlier, the media does not create news, but not all information is considered news. The choice of what information to report gives the media tremendous influence.

3.3.5.1 Stocks and Flows

Stocks	Units	Inflow	Outflow	Units
Media Articles	Articles	Media Reporting	News Lapsing	Articles / Month

The media sector includes only one level, media articles. It collects reported articles holding them while they remain in public memory. When such articles are forgotten and no longer influence opinion, they lapse from memory and flow out of media articles.

3.3.5.1.1 Stock and Flow Equations

Media Articles(t) = Media Articles(t - dt) + (Media Reporting - News Lapsing) * dt

Initial Conditions: Media Articles = 1

Inflows:

1. Media Reporting = (UtilityNews + CongressNews + EventNews + InsideNews + IGNews)

Outflows:

1. News Lapsing = Media Articles / News Lapse Time

3.3.5.2 Converters

Converters	Units	Inputs
IG News	Articles / Month	1. IG Completed Acts. 2. Newsworthiness
Inside News	Articles / Month	1. Informants 2. Info Quality
Event News	Articles / Month	1. LERs 2. Event Newsworth
Utility News	Articles / Month	1. Utility Info 2. Positiveness
Congress News	Articles / Month	1. Congress Releases 2. Release Quality
Event Newsworth *	Articles / Event	1. Step Event 2. Scaling

* Event Newsworth is a converter switch used to help simulate a major event. Scaling is a random function which is normally utilized to specific LER news quality; Event Newsworth switches scaling off if a large event is inputted into the program.

All converter equations within the media sector take the quantity and quality terms of information to calculate the number of articles generated by each information source. Not all information shall be news worthy; currently, several random functions generate quality terms which scale the rate of article generation.

3.3.4.2.1 Converter Equations

O CongressNews = ReleaseQuality * CongressReleases

O EventNews = LERs * EventNewsworth

O IGNews = Newsworthiness * IG Completed Actions

O InsideNews = Informants * InfoQuality

O UtilityNews = Positiveness * UtilityInfo

3.3.5.3 Constants

News Lapse Time is the only constant term within the media sector and represents the average time, in months, which a news article will remain in public memory.

C News Lapse Time = .5

3.3.5.4 External Variables

External Variables	Source Sector
IG Completed Actions	Interest Group
Newsworthiness	***
Informants	Exogenous
Info Quality	***
LERs	Exogenous
Step Event	Exogenous
Scaling	***
Utility Info	Exogenous
Positiveness	***
Congressional Releases	Congressional
Release Quality	***

*** Random functions are used to calculate the quality of provided information. Each information source has an accompanying quality function, generally a random variable between zero and one.

The external variables tied to the media sector are either the information sources from the other sectors or the quality functions accompanying that information. The sources of media articles are interest group activities, Congressional releases, utility information, utility informants, and license event reports. Interest group and Congressional sources are internal to the model while the remaining information is supplied as exogenous inputs which are by definition not in a closed loop and not themselves affected by media articles.

3.3.5.4.1 External Functions

Random scaling functions simulate news quality of the information being supplied to the media. Such function general vary between zero and one, adjusting the quantity of news articles from the sources of information.

O EventNewsworth = If (Scaling+StepEvent) > .5 then 1 else 0

O InfoQuality = RANDOM(0,1,5)

- O Newsworthiness = RANDOM(0,1,6)
- O Positiveness = RANDOM(-.25,1,13)
- O ReleaseQuality = RANDOM(0,1,6)

3.3.6 Exogenous Sector

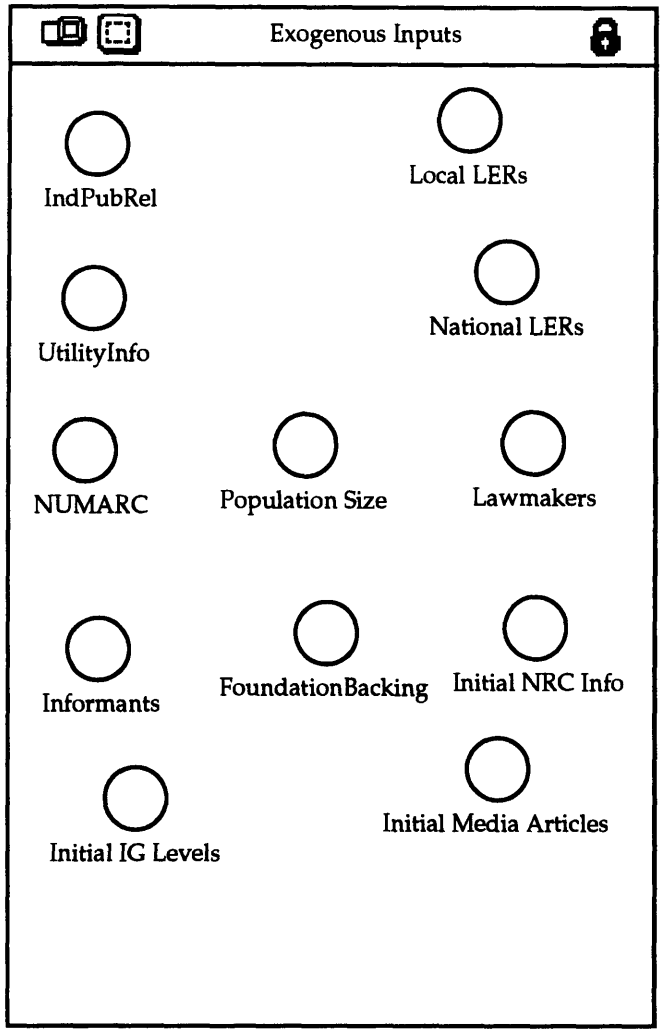

Figure 3.10: Stella Diagram
Exogenous Sector

The exogenous sector contains the external constants which operate upon the SPSRM. Included in this group of factors are variables representing license event reports, industry public relations efforts, utility operating information, informant frequency, NUMARC activities, Foundations Support for interest groups, population of the U.S. and the size of Congress. Below are the variable values.

Exogenous Constants	Units
Foundation Backing	Dollars / Month
Informants	Informant / Month
Lawmakers	Lawmakers
Local LERs	Licensed Event Reports / Month
National LERs	Licensed Event Reports / Month
NUMARC	Actions / Month
Population Size	People
Utility Info	Pages / Month

3.3.6.1 Exogenous Values

C FoundationBacking = 5E4
C Informants = 1
C Local_LERs = 1
C National_LERs = 10
C NUMARC = 4
C UtilityInfo = 1
C Lawmakers = 535
C Population_Size = 250E6

3.3.7 Miscellaneous Calculations

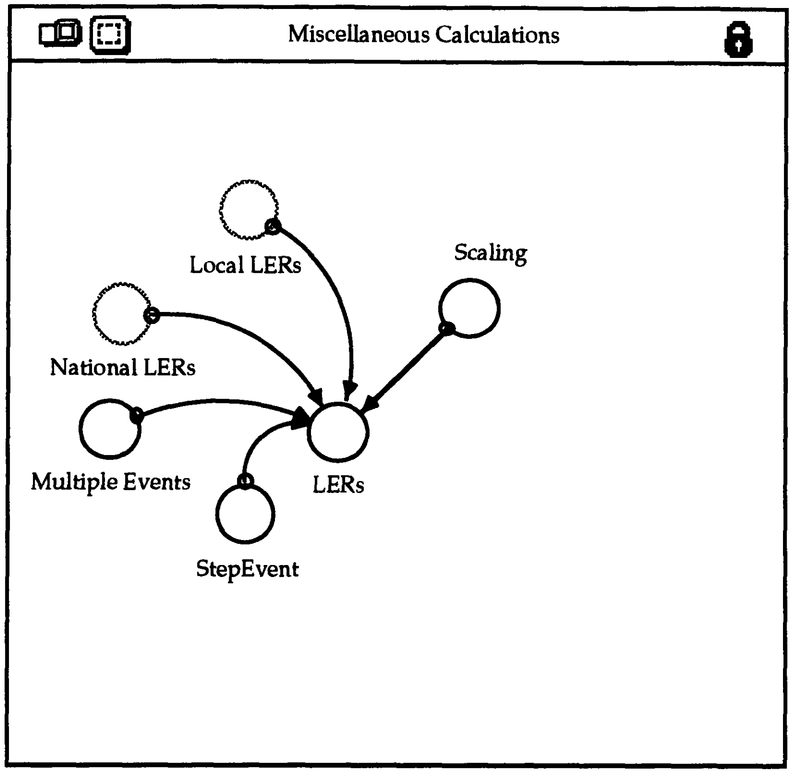

Figure 3.11: Stella Diagram
Miscellaneous Calculations

Currently, only license event reports are calculated within this section. Both the number and magnitude of LERs are combined to develop a quantity representing events. When testing various scenarios, this section is also utilized for inputting large or unusual perturbations into the system: i.e. major accidents, etc.

Chapter 4

4.0 SPSRM Simulations

The SPSRM has been constructed so as to simulate the dynamics of the real nuclear, social system. The process of simulation occurs by integrating the system equations over a period of time, recording the paths of levels and rates so as to observe the system's dynamic behavior. If our model represents reality, then such simulations will enable the study of the system under both normal and hypothetical conditions. It provides a means to test theories of system behavior and the consequences of changing controllable variables.

However, the modeling of system behavior should never be taken as a prediction of the future. The precision of a model such as the SPSRM is not to the predictive degree. In fact, numerical constants within the SPSRM have not been validated with historical data. They have been estimated for simulation purposes. Consequently, numerical output should be taken as references for describing general behavior and not as facts. The SPSRM is designed for studying general system dynamics and investigating how such dynamics vary with changes in system variables and structure. Any significance placed on actual numerical output could be seriously misleading.

This chapter will present several SPSRM simulations in an effort to educate the reader on the performance of the model. The intent is to observe how the system behaves: its normal response, response to abnormal conditions, and its sensitivity to system changes.

Within the text, all SPSRM variables (rates and levels) will not be presented or discussed, only those which are necessary to adequately present model behavior. Each simulations spans ten years. Integrations are by Euler's method, with a delta time of one week. All graphical and tabular data will be presented on a monthly basis.

4.1 Steady-State

Chapter 3 defined the SPSRM. But how does it behave? This section presents a steady-state simulation, which is simply a system integration with constant inputs representing what is considered normal nuclear and social functioning. It is the model as presented in chapter 3. Such a simulation demonstrates how the social system, public and government, operate when the nuclear industry functions reasonably well with no major mishaps. It could be expected that under such conditions public pressure and resulting actions would be minimal and that the system would reach a constant pattern of behavior. Whether such conditions have existed may be debatable, but dynamics prior to the Three Mile Island accident, especially 1960's and early 1970's, might approximate such behavior.

4.1.1 System Overview

Although more detailed graphs will be utilized for highlighting sector outputs under various simulations, a standard overview will be presented here. Time series of four levels are graphed: Concerned Public, IG Completed Actions, NRC Concern, and NRC Regulation. These levels provide a general representation of the model, showing both public and government actions and perceptions.

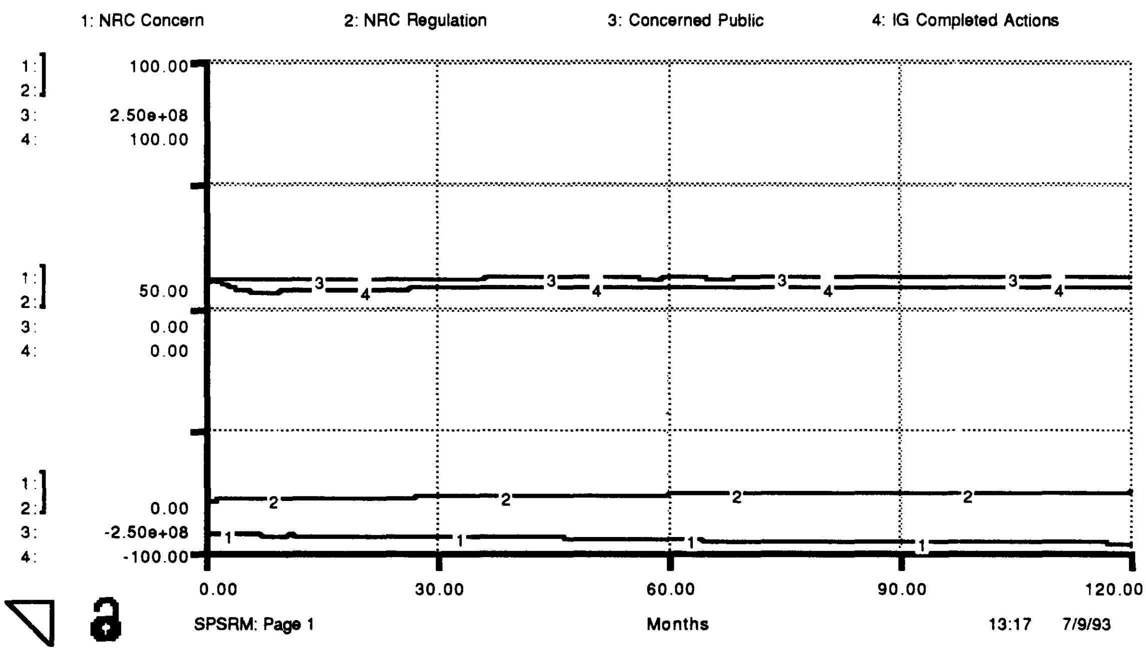

Figure 4.1: Steady-State System Overview

The results shown in Fig. 4.1 indicate that the system remains fairly constant and stable with a constant stimulus. With no abnormal events to stimulate activity, concerns and actions become routine and relatively constant. The number of concerned individuals stabilizes between 15 and 20% of the population. Such constant support causes interest group activities to stabilize, which, in turn, places relatively constant public pressure upon the government. Since the industry is functioning well and public pressure is slight, the NRC's concern maintains a gradual decline over the span of simulation. Regulation increases but at a very slow pace -- less than 1% per year. The increase stems from accumulated experience from the worldwide nuclear industry.

Such a response seems plausible. With a well functioning industry, confidence in industry performance would grow, creating little incentive to dramatically alter regulations. Additionally, without a stimulus for converting people, a core of concerned individuals would probably remain but with little change.

4.1.2 Levels and Rates

Although the levels shown remain relatively constant, flows of people, actions, and concern still fluctuate. All that is required for a level to remain relatively stable is that the sum of a level's inflow and outflow total to zero on average. A look at the concerned public and public converting provides a good demonstration, as shown in Fig. 4.2.

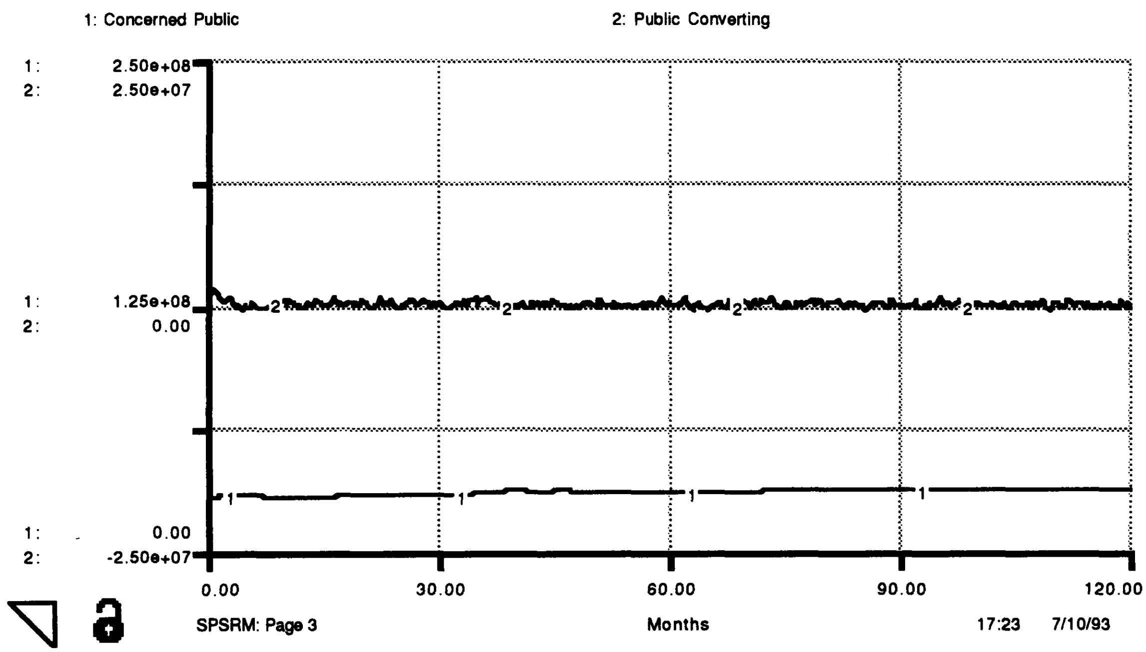

Figure 4.2: Steady-State Public Sector

Public converting appears somewhat erratic, but a careful observation shows that it oscillates around zero, balancing a consistent but small conversion of people from unconcerned to concerned and vice versa. (Note that public converting represents both in and out flows whereas with some levels this is split between two separate functions.) Under these "steady-state" conditions, most levels within the SPSRM exhibit such behavior. The exceptions are primarily NRC actions, regulating and regulation, and media articles, as demonstrated by Fig. 4.3. Regulating fluctuates but is always positive, and since discarding of regulation is zero, regulation always grows instead of remaining constant. Media articles continually fluctuate because the drivers for news quality are random functions constantly varying.

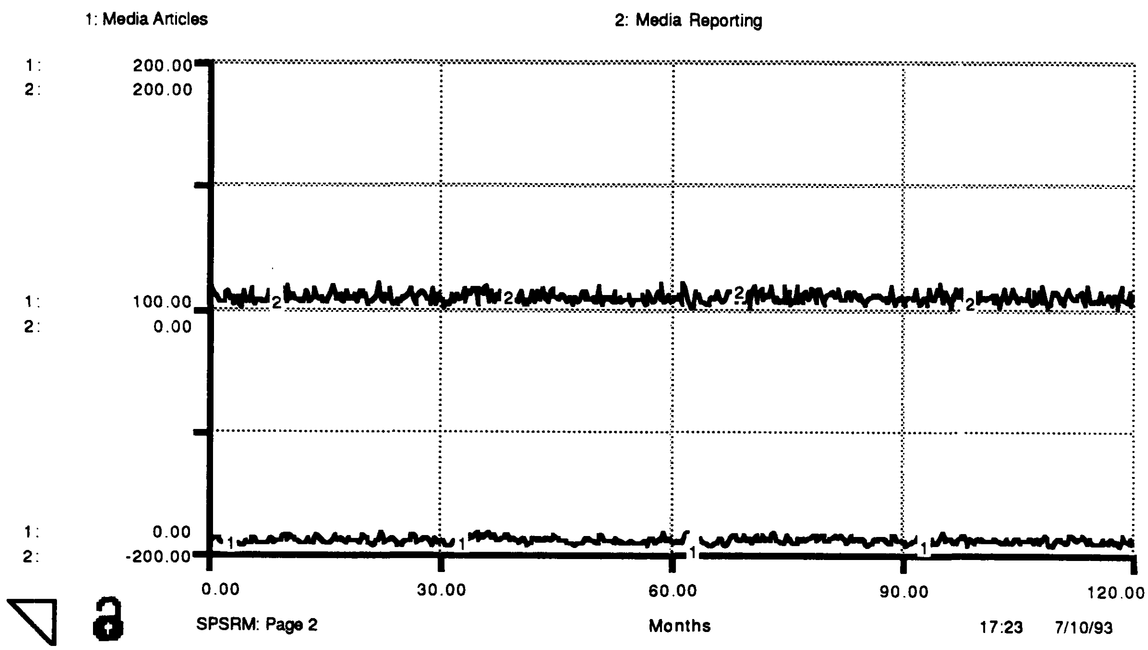

Figure 4.3: Steady-State Media Sector

As can be seen in Fig. 4.3, the level of media articles within public memory always fluctuates, although small on average.

4.2 System Disturbance

If the world were perfect and no nuclear incidents occurred, a steady-state response might be all that is required. But in fact, it is the incidents and accidents, and the potential for such, which drive most social responses to the nuclear industry. Consequently, of more importance is how the SPSRM responds to a significant disturbance such as a major nuclear accident or event. This section reviews such a response.

As discussed in chapter 3, the model incorporates events and incidents through the reporting process mandated by 10 CFR 50 -- License Event Reports. Within the model, the NRC, interest groups, and the media receive LER notices: the NRC by law and interest groups and the media through their own sources or through the Freedom of Information Act. LERs contain both a frequency and scaling factor which combine to determine LER influence. To simulate a major event, a one month impulse representing a single event with a scaling of 100 has been inputted. Such scaling represents a site incident causing significant damage but no offsite harm. The event occurs in month 50, and, as before, the simulation runs for 120 months.

4.2.1 System Overview

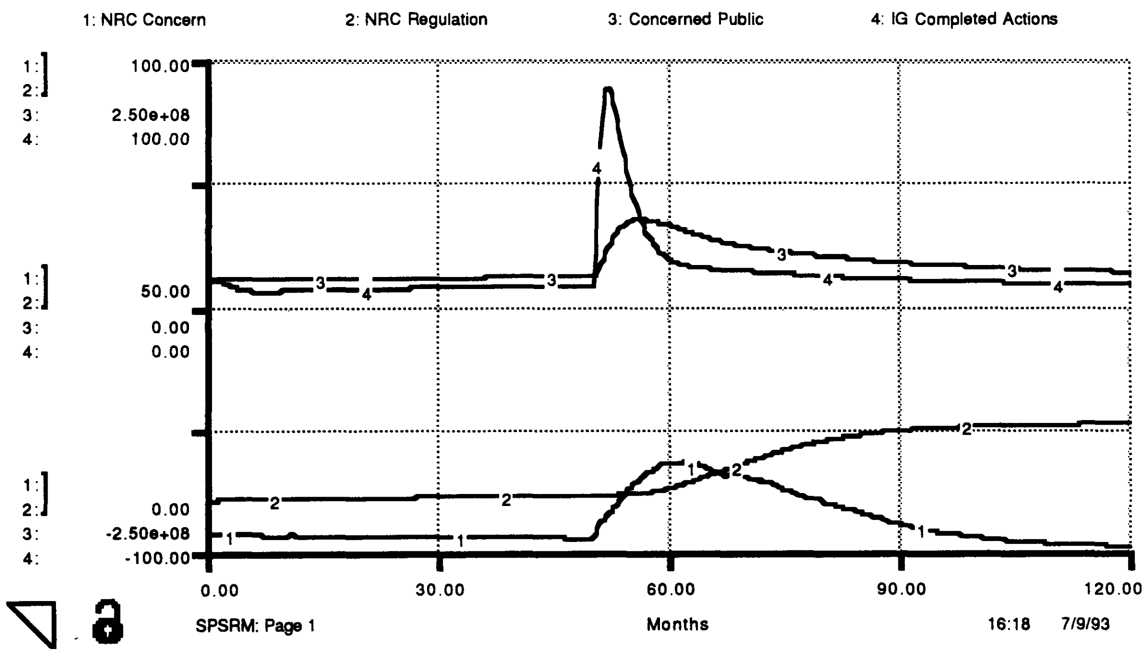

Figure 4.4: Event Overview

4.2.1 System Overview

A comparison between the steady-state and event overviews in Fig. 4.4 reveals the significant impact which the input causes. Although the accident simulates a site event only, any major nuclear incident raises the specter which many envision from a nuclear event. Nuclear plants are built and operated with the expectation that no harm will come to the public. When an event posses that potential, public confidence is questioned, fears grow, and pressure mounts for action to reassure public safety. The graph above demonstrates the changes in public and government concern and the resulting actions which follow the incident.

4.2.2 Public Response

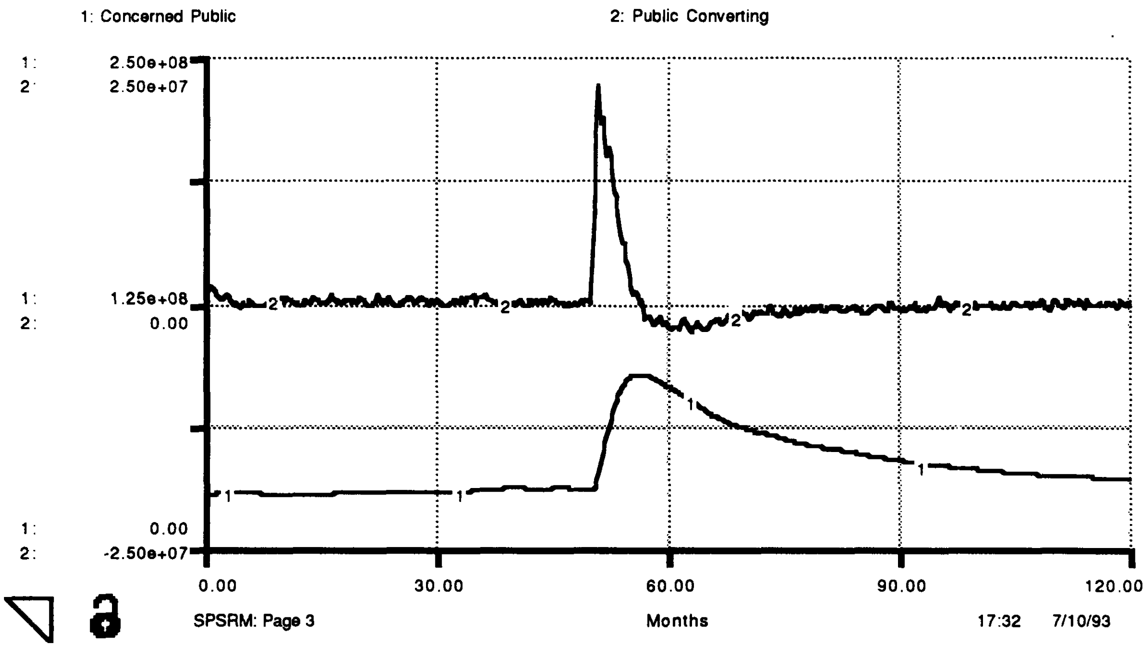

Figure 4.5: Public Sector, Event

The origins of social pressure upon the nuclear industry lies with the general public, whose concern supports public action which eventually may alter government activities. Before the disturbance, the concerned population had stabilized around 27 million individuals. Within one and a half months of the event, public converting has risen from an average of zero to a peak of 18.8 million people/month. The concerned public peaks four and a half months later, at month 56, when public converting becomes negative. At the end of 120 months the level of concerned individuals is again stabilizing but at 33.6 million people, 24% above pre-event.

4.2.3 Interest Group Response

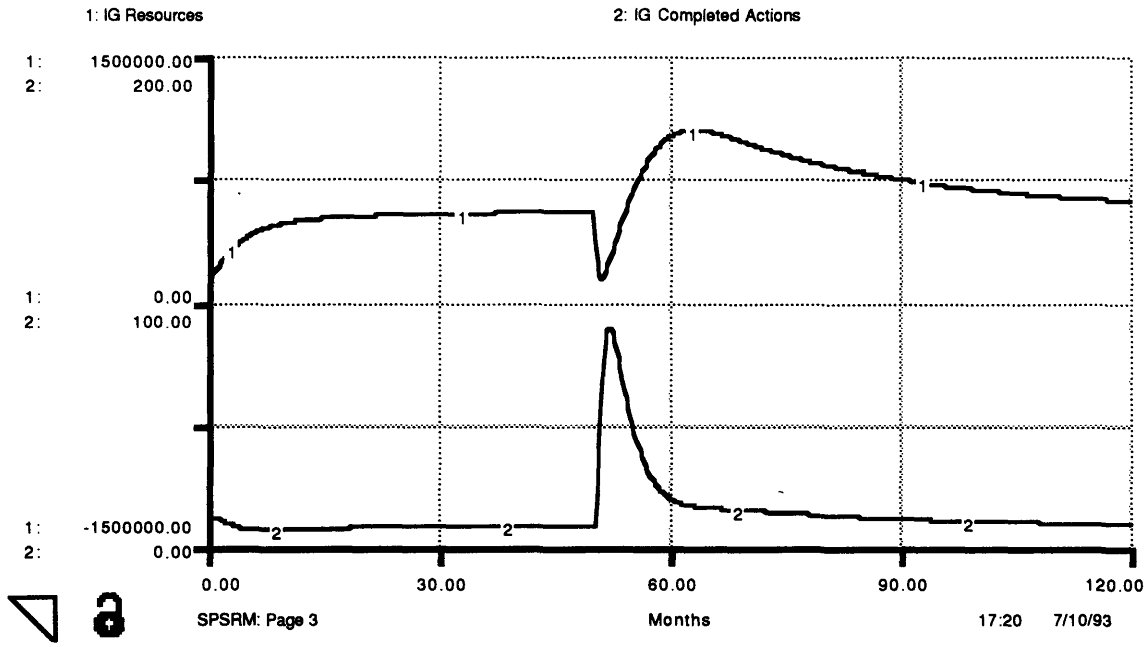

Figure 4.6: Interest Group Sector, Event

Fig. 4.6 shows that prior to the event interest group completed actions had stabilized around 7 per month. Note that these actions are the means of public influence within the SPSRM. After the incident, actions soared peaking at 89 two months later, then gradually declining to a level of 8.35 at month 120. The sharp rise in interest group activity does not follow a sharp rise in resources but, instead, increased spending of available dollars. Public conversion and support are not instantaneous to the accident. Consequently, if interest groups wish to utilize the event to highlight their concerns, they must spend available resources immediately and utilize new donations as received. Such strategy synergetically boost interest group influence since a concerned Congress, NRC, and public are more receptive to public pressure than when unconcerned.

4.2.4 Congressional Response

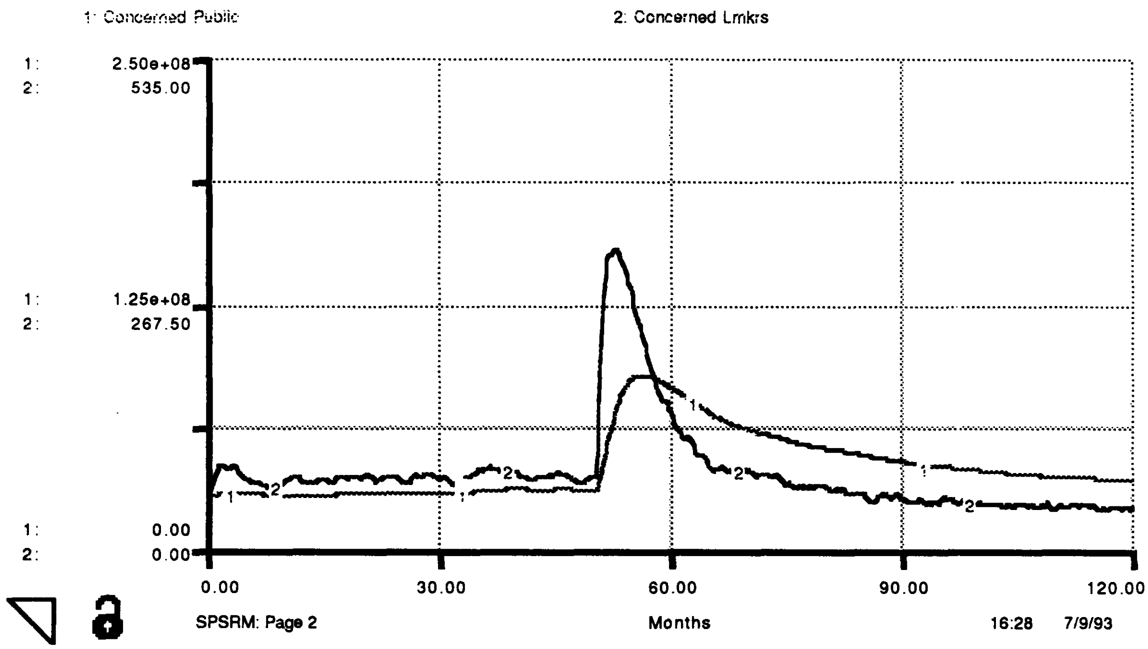

Figure 4.7: Concerned Congress with Concerned Public, Event

Congress responds much the same as the general public except that the swing of concern is more pronounced -- both in amplitude and speed. It takes just 3 months for concerned lawmakers to peak at 325, rising from a steady-state average of 70. Ten months later, less than 100 lawmakers are concerned, less than 70 the following year. At the end of 120 months approximately 40 lawmakers remain concerned. The sharp rise and fall reflects the nature of Congressional interest. The decline of Congressional concern below the pre-event value occurs because the increased level of government regulation eases many lawmakers' worries.

4.2.5 NRC Response

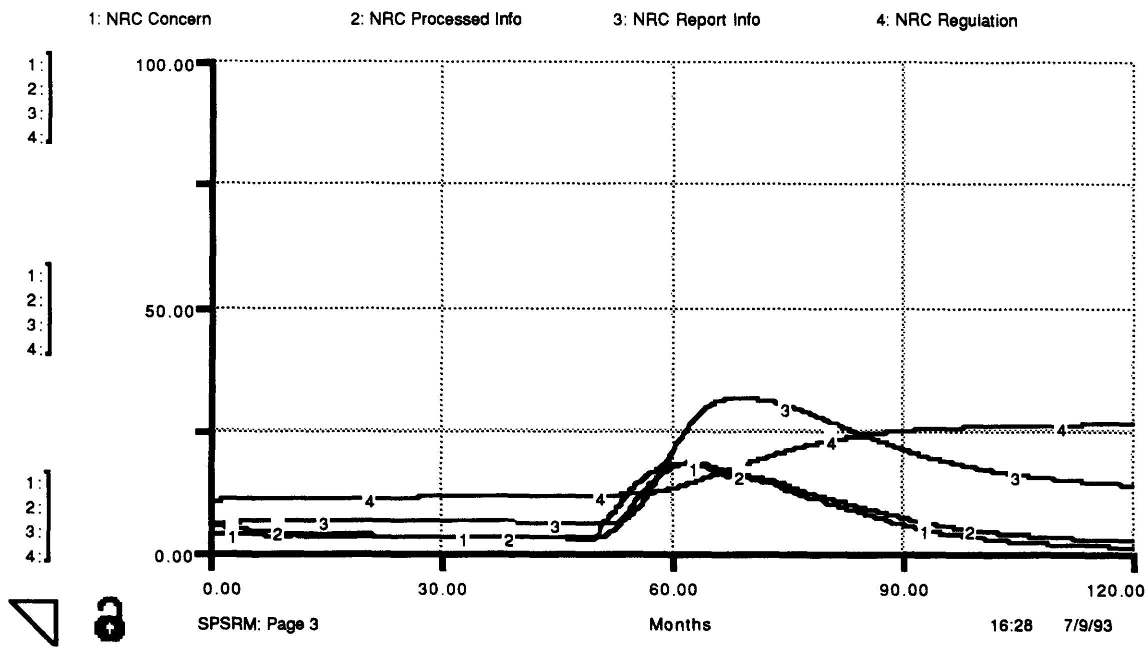

Figure 4.8: NRC Concern, Processed Information, Reported Information, & Regulation; Event

The model's representation of the NRC shown in Fig. 4.8 demonstrates not only the quantity of change that an event might initiate but also the lags inherent between initiation and implementation. NRC concern begins to rise immediately following the event peaking at 18, from an initial 2.5, one year after the event. Processed information mirrors concern with about a month lag. Reported information begins to rise about three month after the event and peaks a year and a half later. The regulation rate begins to increase about six months after the event and continues at an accelerated pace for about three years. One large event triggers NRC concern which drives regulatory actions for over four years, eventually doubling the level of regulation.

4.2.6 Media Sector

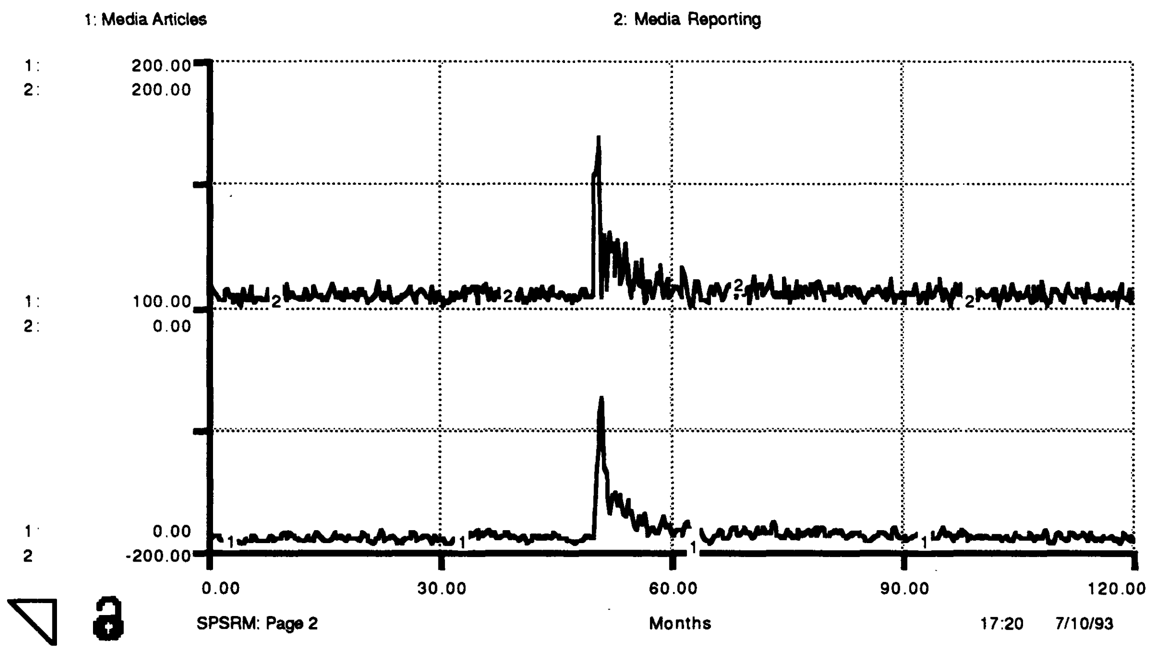

Figure 4.9: Media Articles with Media Reporting Event

A nuclear accident is news. Because a catastrophic failure could cause serious public harm, the media assumes responsibility for investigating and reporting the story behind any major nuclear accident. Included is not only an effort to present the facts of the accident, but to report various credible actors accounts and concerns. Consequently, the event and the activities of interest groups, which increase in response to the event, create a significant rise in media reporting: peaking within the first month but remaining elevated for ten months to a year.

4.3 Model Sensitivity

In the previous section, introducing a disturbance altered the dynamics of the system. Rates changed, and levels followed different paths. In essence, the model demonstrated its sensitivity to industry performance. But changing any variable or structural tie might alter system behavior. Learning which components are integral to system behavior and within what ranges such components can operate would enhance understanding of both the model and the system, highlighting not only where the system might be manipulated but also the models strengths and weakness in emulating reality.

Three component types comprise the SPSRM: structural members such as stocks, flows, and information transfers; exogenous variables such as industry performance and activities; and system variables such as time constants and conversion coefficients. This section presents simulations under a variety of component situations. All simulations within this section retain the event as inputted in section 4.2.

4.3.1 Structural Variations

It is not the intention of this section to rebuild the model but rather to investigate the importance of two sectors by simulating the model without their input. Although uncertain of the precise impact, the media and interest groups wield significant influence within the nuclear, social system. To test that influence, the following simulations are run without these sectors (removed one at a time).

4.3.1.1 Media Sector

Figure 4.10 presents a simulation of the SPSRM with media reporting equal to zero, effectively eliminating media articles from the model. With the information which forms and reinforces opinions sharply curtained, fewer concerns and actions develop, especially within the government. The event alone initiates an increase in NRC concern, but without the media to drive public concern and reinforce public pressure within Congress and the NRC, there is little pressure for the NRC to greatly alter existing regulations. Without social communications, the NRC's response to such an event need not be as public as a change in regulation.

The public sectors still react, but with much less fervor. Interest groups receive event information and influence public, Congress and the NRC, but without media reinforcement, such actions produce fewer results.

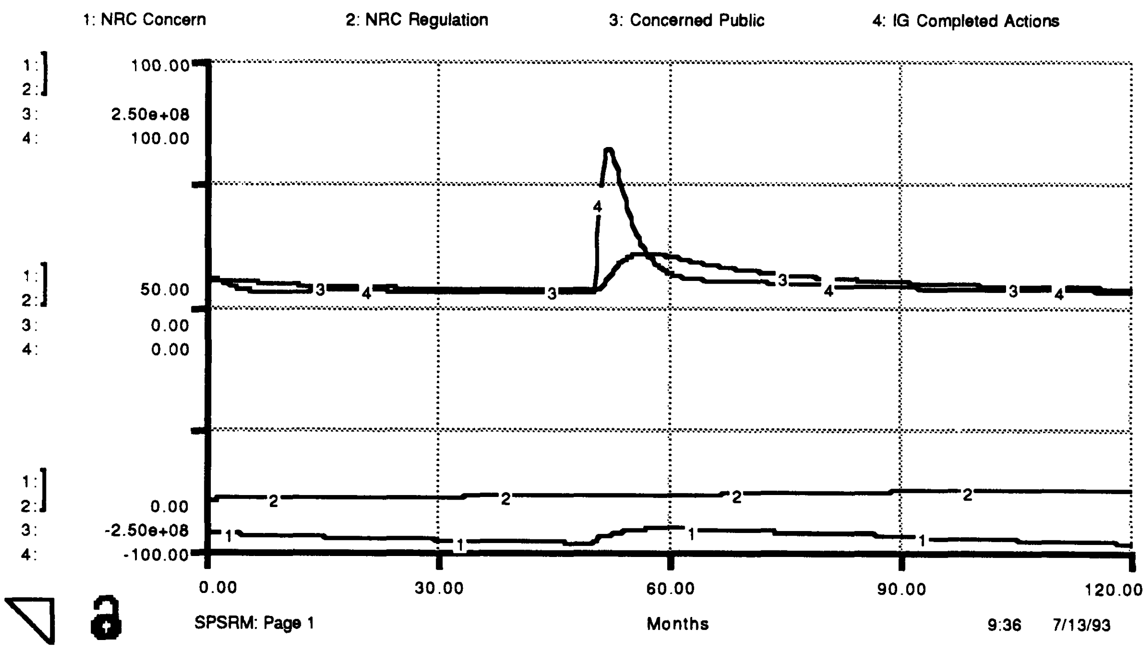

Figure 4.10: No Media Overview

4.3.1.2 Interest Group Sector

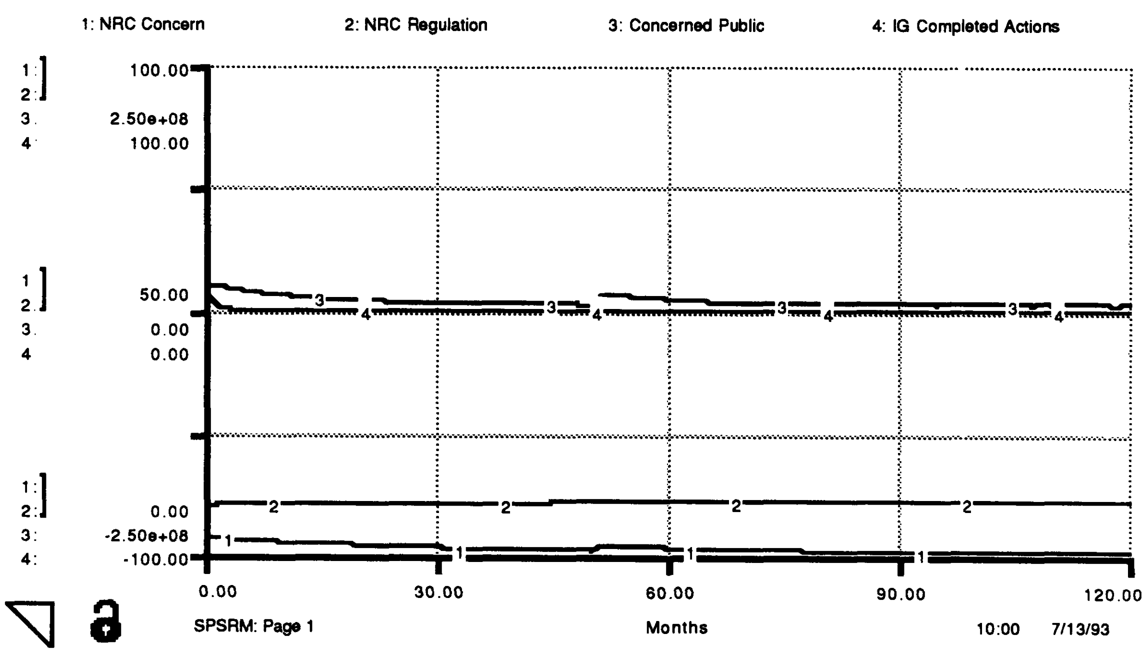

Figure 4.11: No Interest Groups, Overview

Figure 4.11 presents a simulation with no interest group actions. (Here IG Acting is set to zero.) Without the public action, which interest groups represent, virtually no governmental action occurs as a result of the event. There is simply no social pressure or public mandate to force additional government oversight or regulation. Some public concern develops (small perturbation) because the media reports the event, but with no groups to publicize or advocate the potential harm of such an event, few means to raise public concern exist.

Would the world mimic such simulations if no media or interest groups existed? Perhaps not, but the dynamics of the former Soviet Union might reinforce such a view of media and interest group influence upon the nuclear system. Additionally, US history before anti-nuclear interest groups became common might also correlate to such a perspective.

4.3.2 Exogenous Variable Sensitivity

The exogenous sector provides the inputs for utility and industry performance, variables which affect the social system but -- within the SPSRM -- are not themselves altered by social behavior. (As noted before, in the larger nuclear system such variables are influenced by the social system's behavior, but the SPSRM does not encompass such mechanisms.) This section presents a series of sensitivity runs for each exogenous industry variable. The runs compare how system levels change with varying exogenous inputs. In each section which follows, the parameters variation runs from one half to double the current parameter value.

4.3.2.1 Utility Information

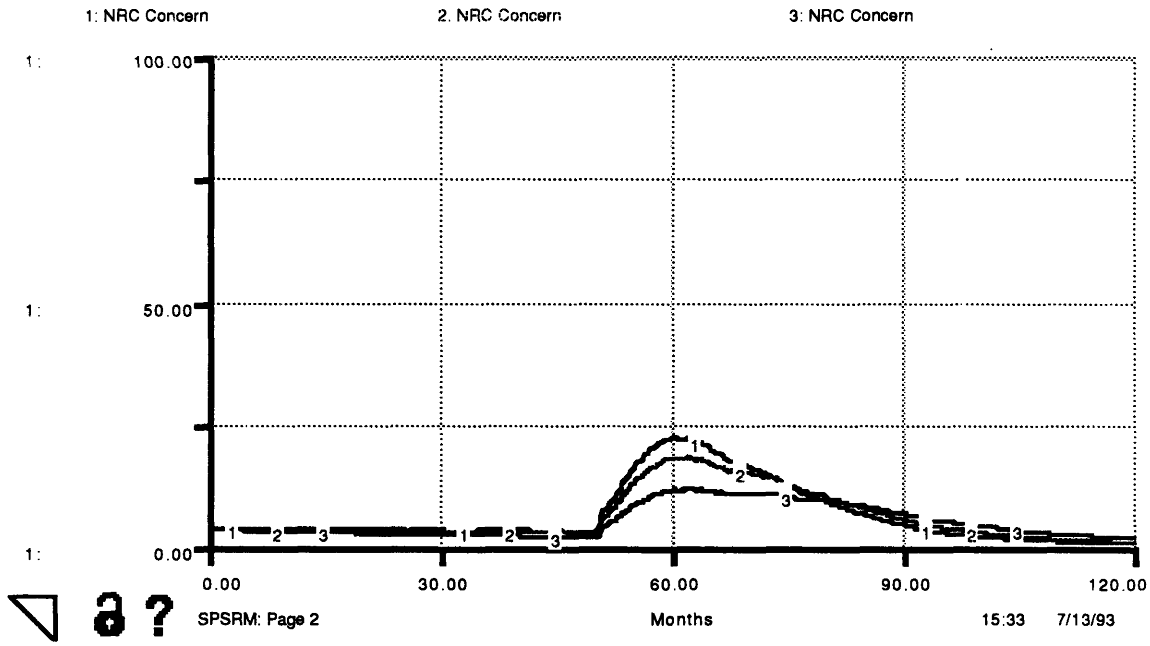

Figure 4.12: NRC Concern
Utility Information [.5, 1, 2]

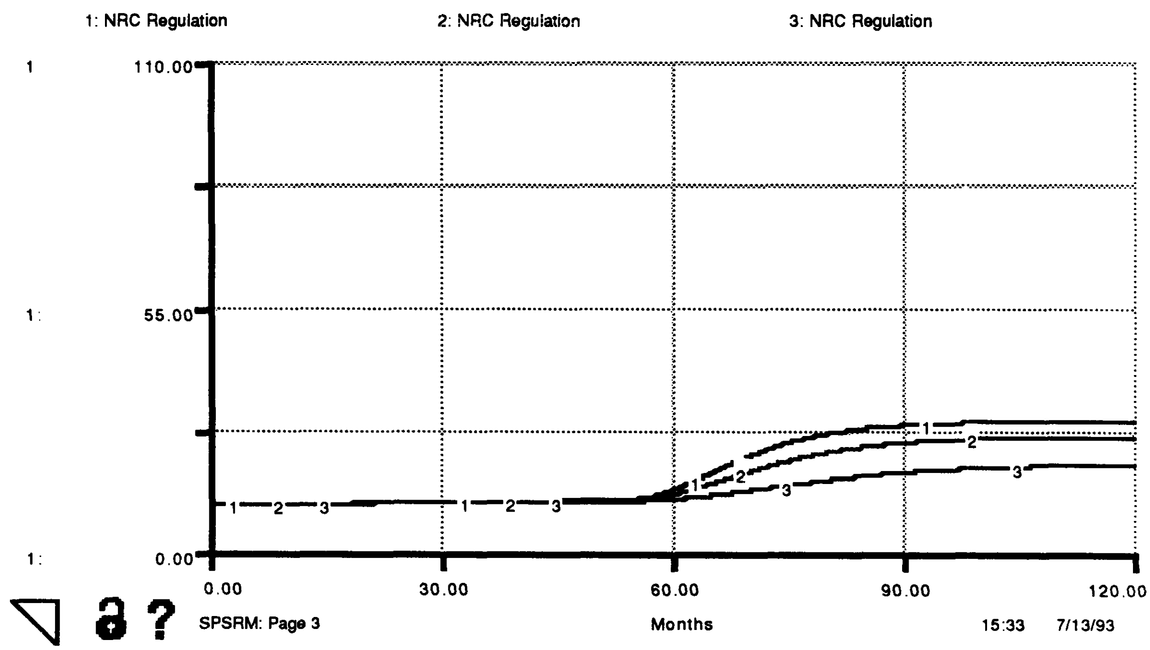

Figure 4.13: NRC Regulation
Utility Information [.5, 1, 2]

On a routine basis, the utility provides a variety of information describing plant conditions and operating history to the NRC. One premise of the SPSRM is that cooperation between the NRC and the utility lessens NRC concern over operations. Consequently, the behavior depicted in Figures 4.12 and 4.13 fits the expectation that a higher level of utility information would lessen the rise of concern and regulation following a significant event. The magnitude of change is small, however. Even though output varies ten to fifteen percent, the halving and doubling of standard utility information does not drastically alter system behavior.

4.3.2.2 NUMARC

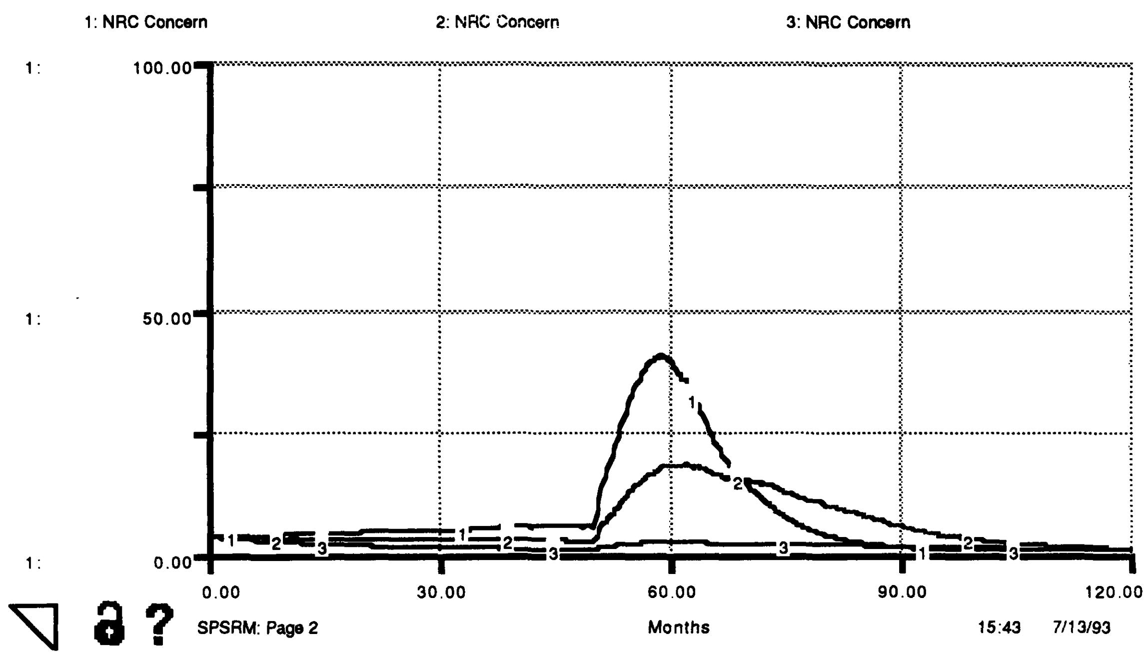

Figure 4.14: NRC Concern
NUMARC [2, 4, 8]

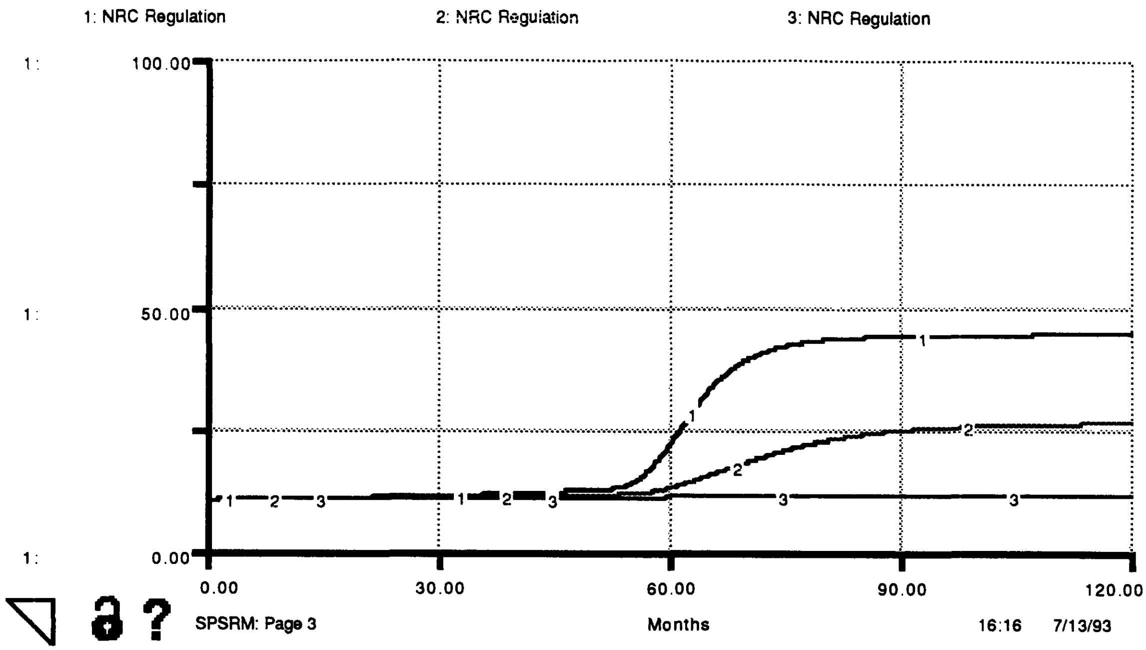

Figure 4.15 NRC Regulation
NUMARC [2, 4, 8]

The Nuclear Management and Resource Council consolidates industry efforts to communicate with the NRC. Within the SPSRM, NUMARC efforts build NRC confidence in the industry, lowering the drive for additional regulation. Figures 4.14 and 4.15 show that halving NUMARC activities more than doubles NRC concern and regulation and doubling efforts almost eliminates a rise in concern following an accident. Figure 4.14 also demonstrates the time behavior of NRC concern. There is a general correlation between amplitude and time response of NRC concern: as the amplitude of concern increase the duration of elevated concern decreases and vice versa.

Note, however, that NUMARC efforts primarily affect the NRC only. Figure 4.16 below shows virtually no change in public concern as NUMARC activities change.

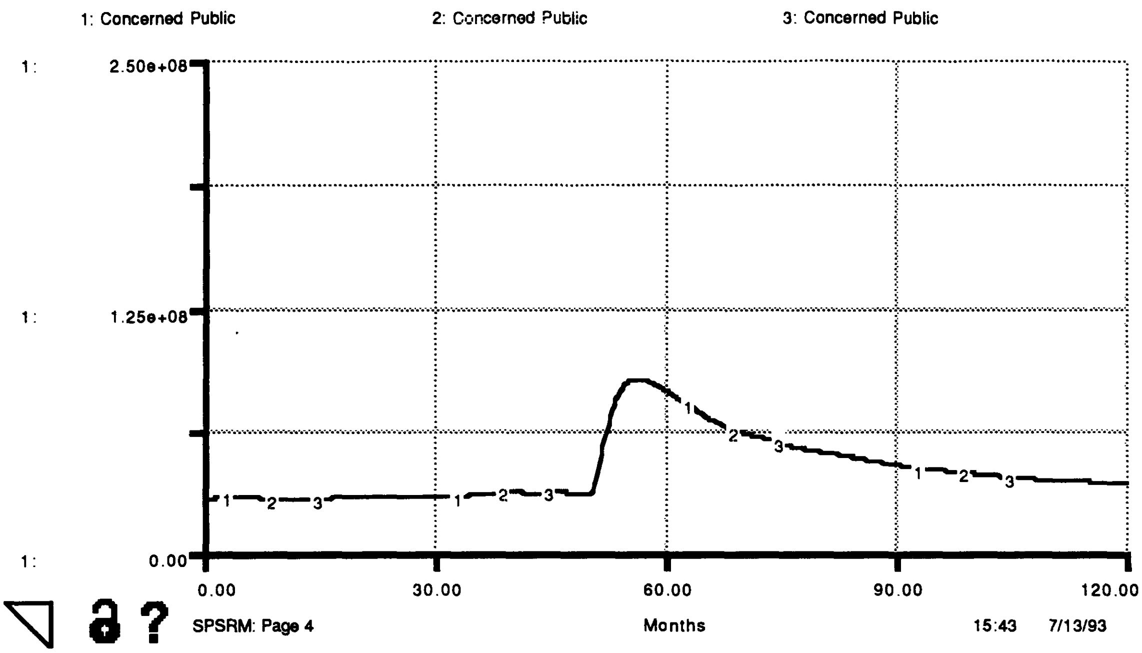

Figure 4.16 Public Concern
NUMARC [2, 4, 8]

4.3.2.3 Informants

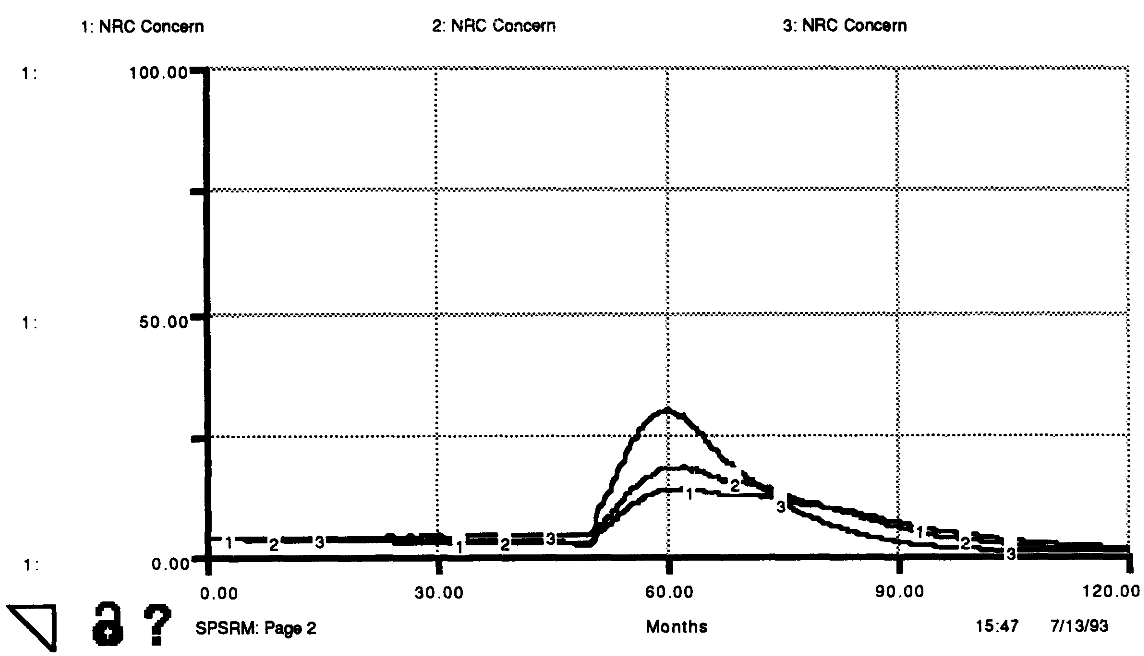

Figure 4.17 NRC Concern
Informants [.5, 1, 2]

Informants represent utility personnel who directly report their concerns about plant safety and operation to the NRC. Such reports would naturally increase NRC concern, as shown by the Fig. 4.17 above. What is interesting though is that an increase in informants creates a much larger change in NRC concern than does a decrease in such reports.

Because informants also speak to the press, they also have some impact upon public concern, but as can be seen by Fig. 4.18, it is hardly noticeable.

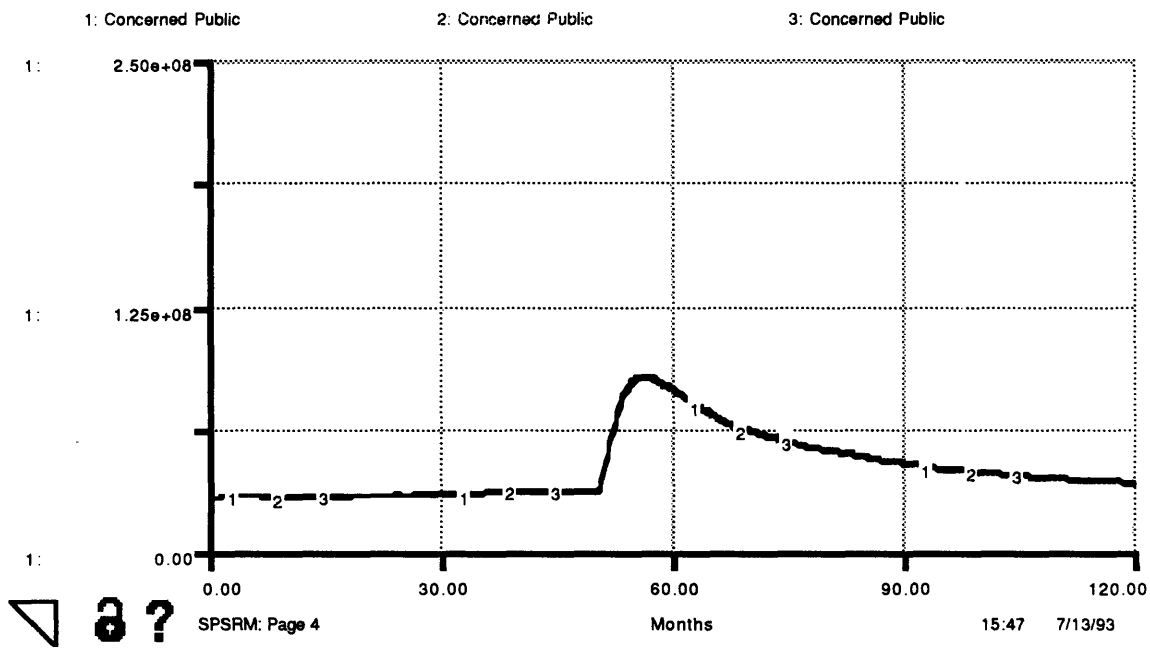

Figure 4.18: Public Concern
Informants [.5, 1, 2]

4.3.2.4 License Event Reports

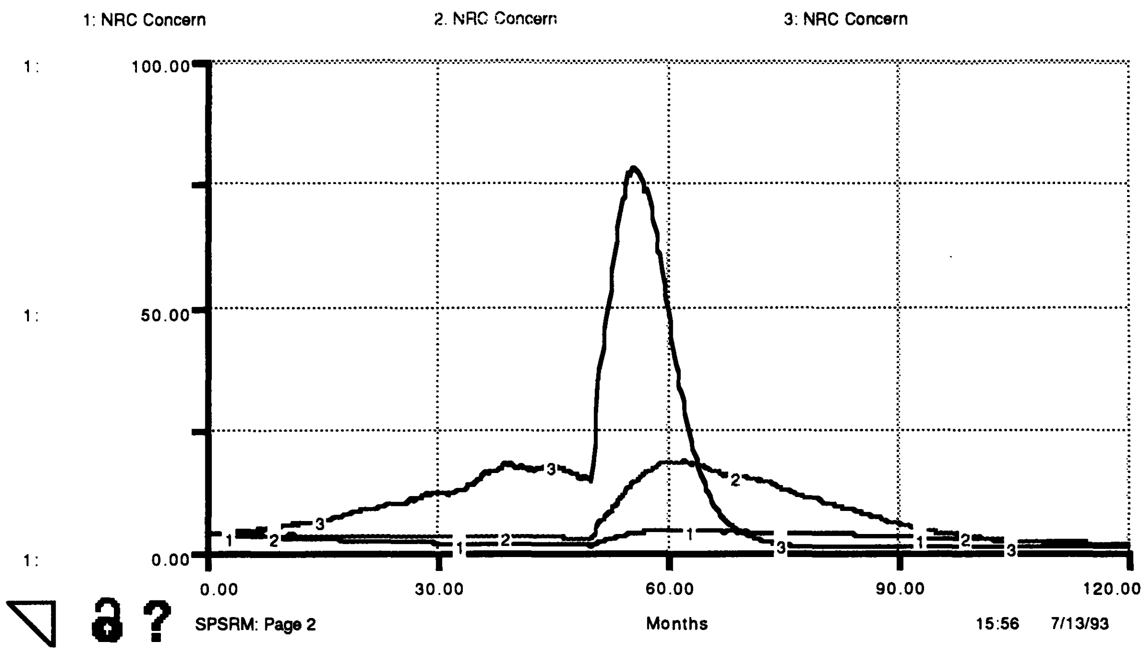

Figure 4.19: NRC Concern
LERs [5, 10, 20]

LERs signify a deviation from technical specifications. An increase in such reports indicates that utilities are having difficulty operating under specs and implies a deterioration of safety. Figure 4.19 shows that a doubling of the normal LER rate significantly increases concern before the event, which then dramatically affects an already worried NRC. Such behavior implies that if plant performance where already shaky, then a major incident could trigger drastic reforms in the regulatory process, a highly plausible scenario. (Here operates the principle that if already concerned, an event triggers significantly more worries than if unconcerned, when the same event triggers few worries.)

Figure 4.20 below shows that a troubled industry, as indicated by a high rate of LERs, also heightens public concern. More events spark interest group actions and media attention, providing the information which alters public opinion.

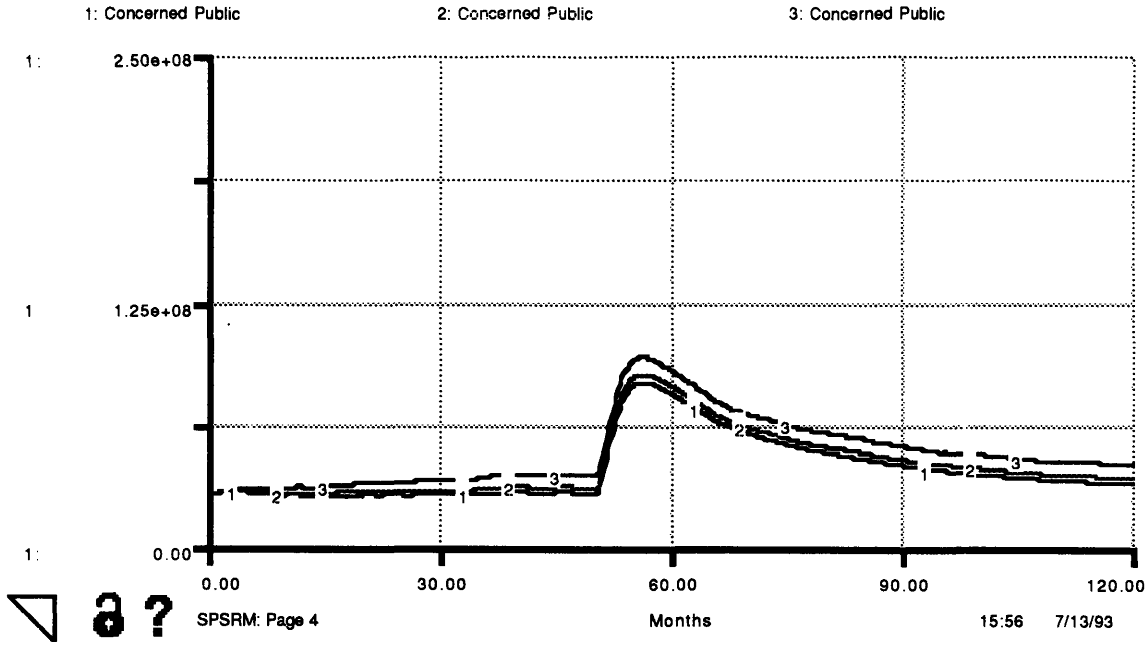

Figure 4.20: Public Concern
LERs [5, 10,20]

4.3.2.5 Industry Public Relations

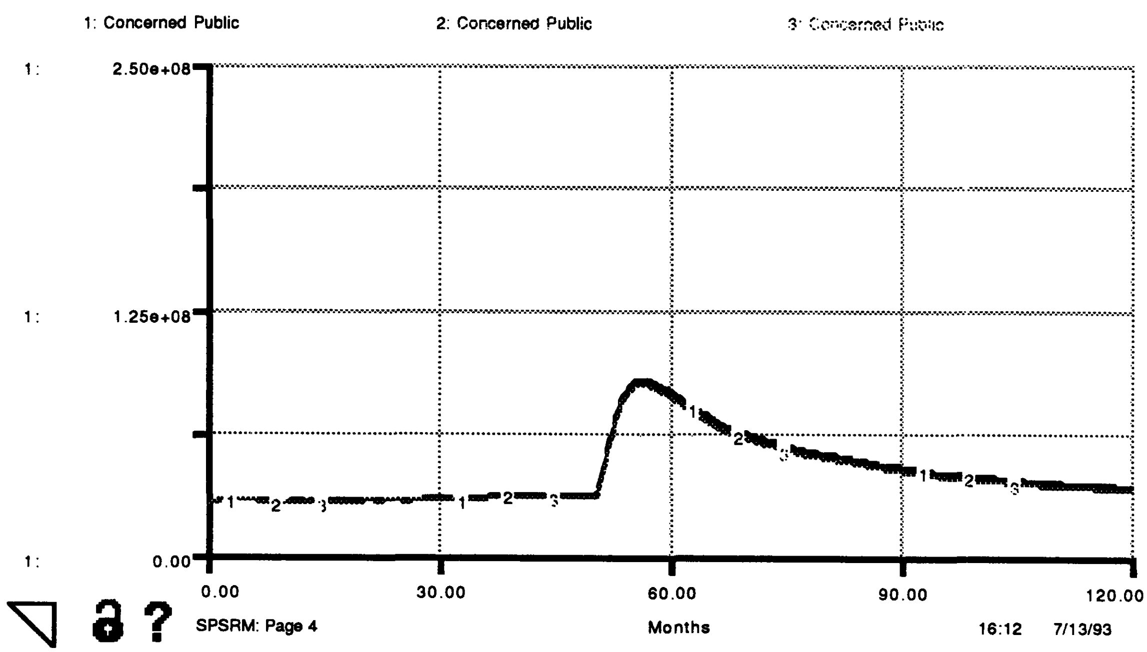

Figure 4.21: Public Concern
Industry Public Relations [1, 2, 4]

Industry Public Relations represents the industry's efforts to persuade public opinion in support of nuclear power. Impacts on regulation or government concern are indirect byproducts of less public concern and fewer public actions. However, Figures 4.20 and 4.21 indicate that halving or doubling of public relations efforts have negligible impact upon public concern.

4.3.3 Internal Variables

Where as the exogenous section reviewed model sensitivity to inputs from beyond the social system boundaries, this section looks at sensitivity to variations in internal parameters. Each sector within the model contains several parameters which quantify the rates and calculations that define material and information flows. Although all such parameters will not be presented here, those which significantly affect the system shall be -- along with a sample of others to enhance understanding of the model's operation. Variables are presented by sector; only within the public sector will all variable parameters be reviewed.

4.3.3.1 Public Sector

The four constants contained within the public sector guide public converting and public donating: the development of concern and its influence. Because the public sector is the foundation for social pressure, the model tends to be very sensitive to changes in this sector's parameters.

4.3.3.1.1 Public Constant

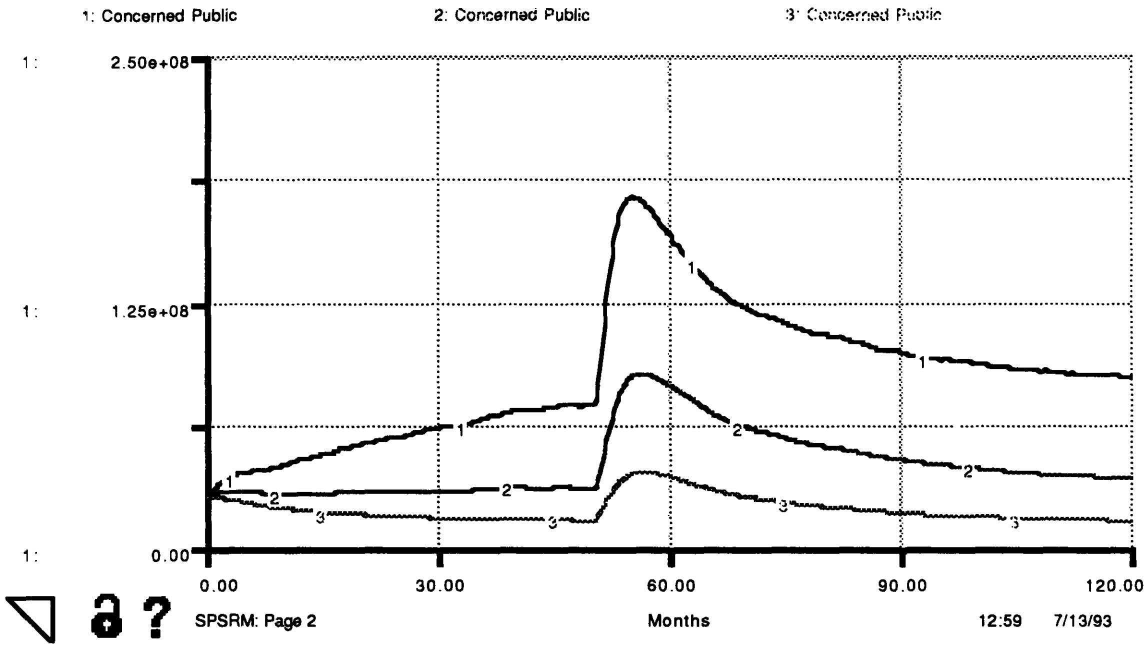

Figure 4.22: Public Concern
Public_Constant[.002, .001, &.0005]

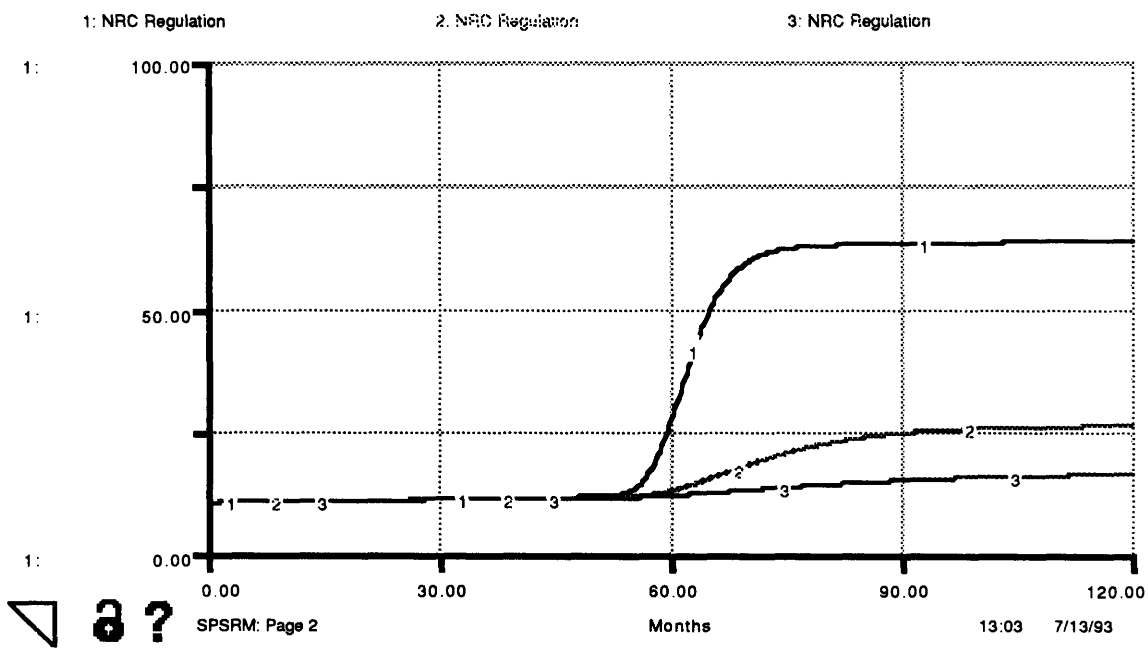

Figure 4.23: NRC Regulation
Public Constant [.002, .001, & .0005]

The public constant specifies the degree of influence which incoming information has upon the general public. It is the basis of public opinion, and as Figures 4.22 and 4.23 show, the model is quite sensitive to public constant variations. Since public opinion supports social pressure, large changes in public concern are reflected in regulatory output.

4.3.3.1.2 Public Memory

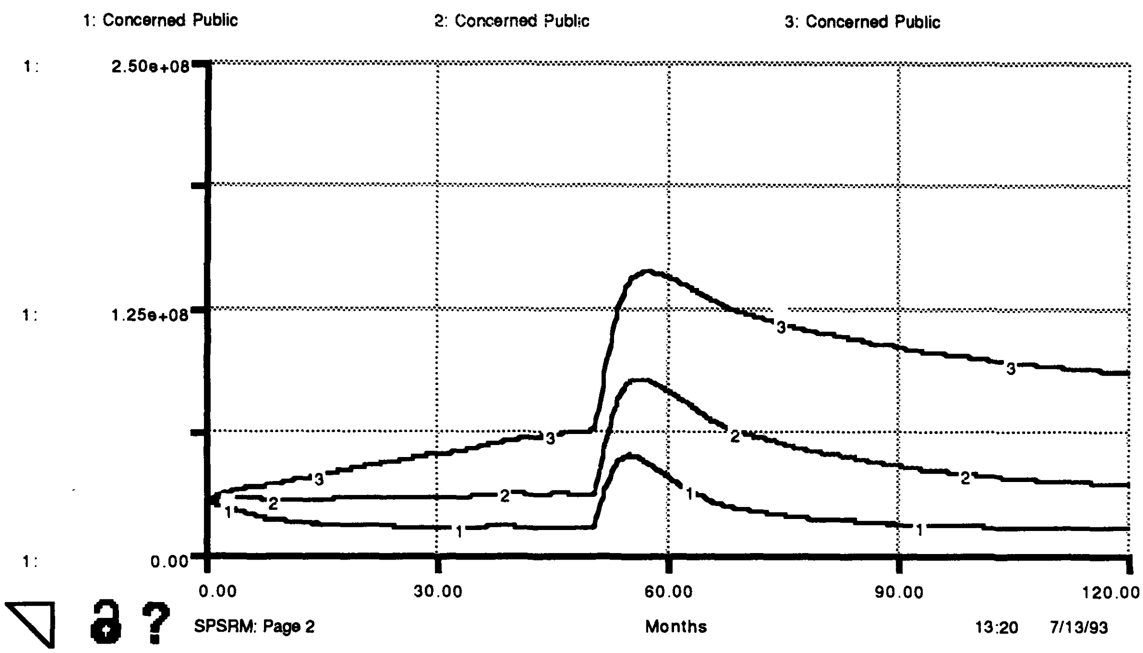

Figure 4.24: Public Concern
Public Memory [6, 12, 24]

Because public memory specifies the rate at which individuals forget the information which cause them to become concerned, it is significant in controlling the level of public concern, as here shown. A short memory leads to lower concern levels because converted people readily forget and convert back to the unconcerned, vice versa with lengthy memories. In essence, public memory weights the original conversion process because length of memory affects the rate of conversion necessary to maintain a given level of concern.

4.3.3.1.3 Average Public Donation

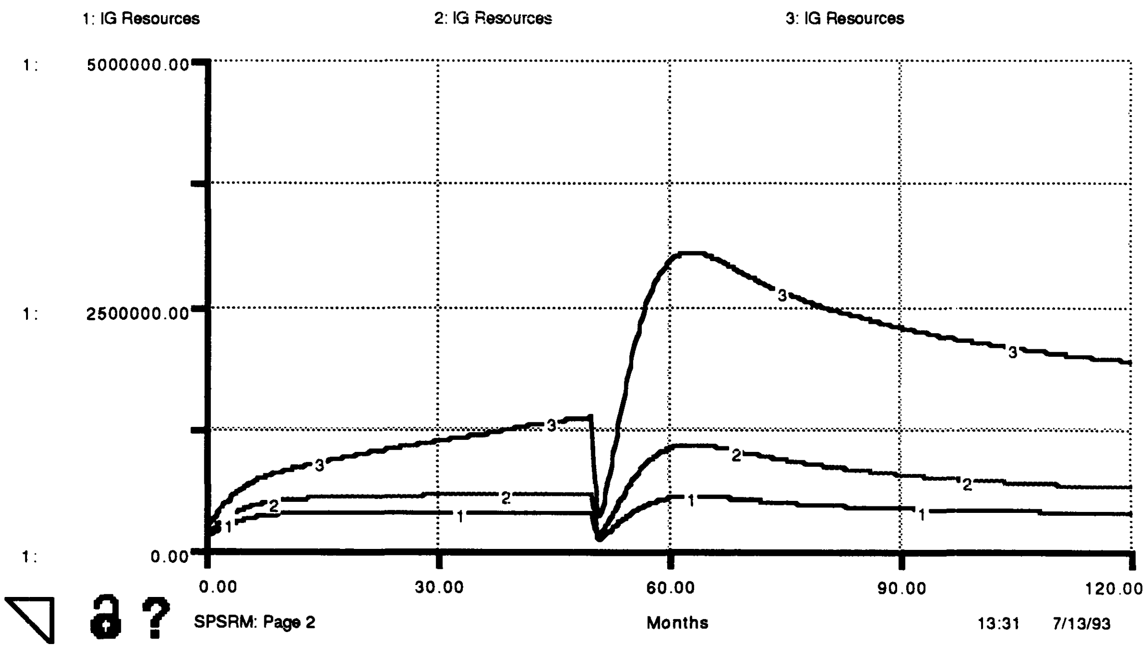

Figure 4.25: IG Resources
Ave Pub Donation [.5, 1, & 2]

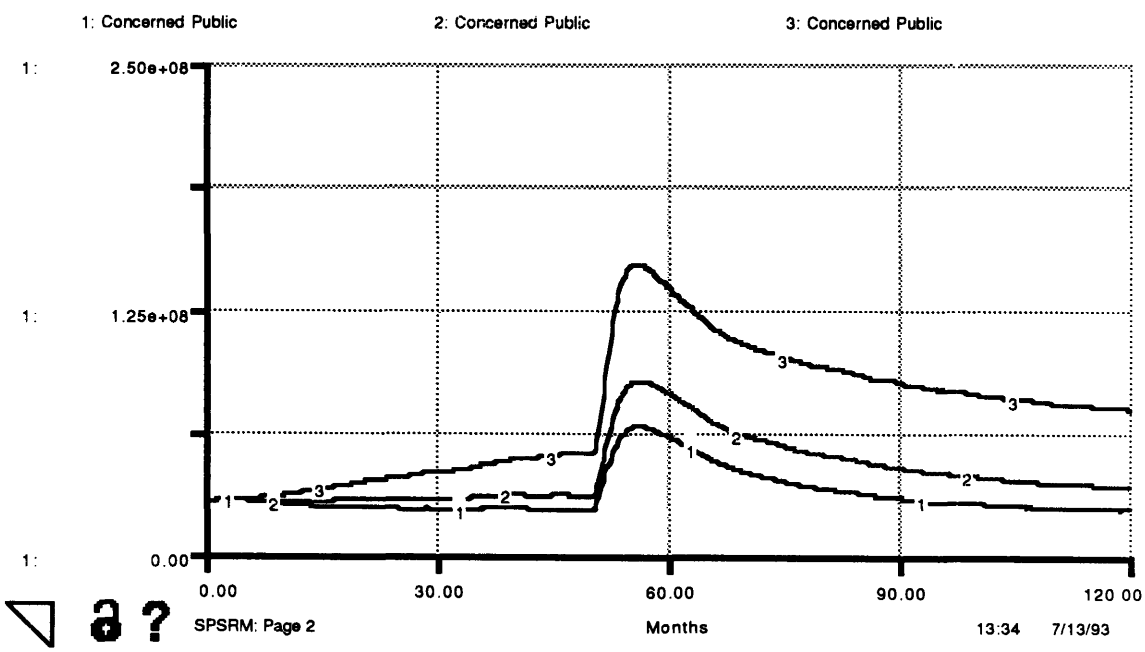

Figure 4.26: Public Concern
Ave Pub Donation [.5, 1, & 2]

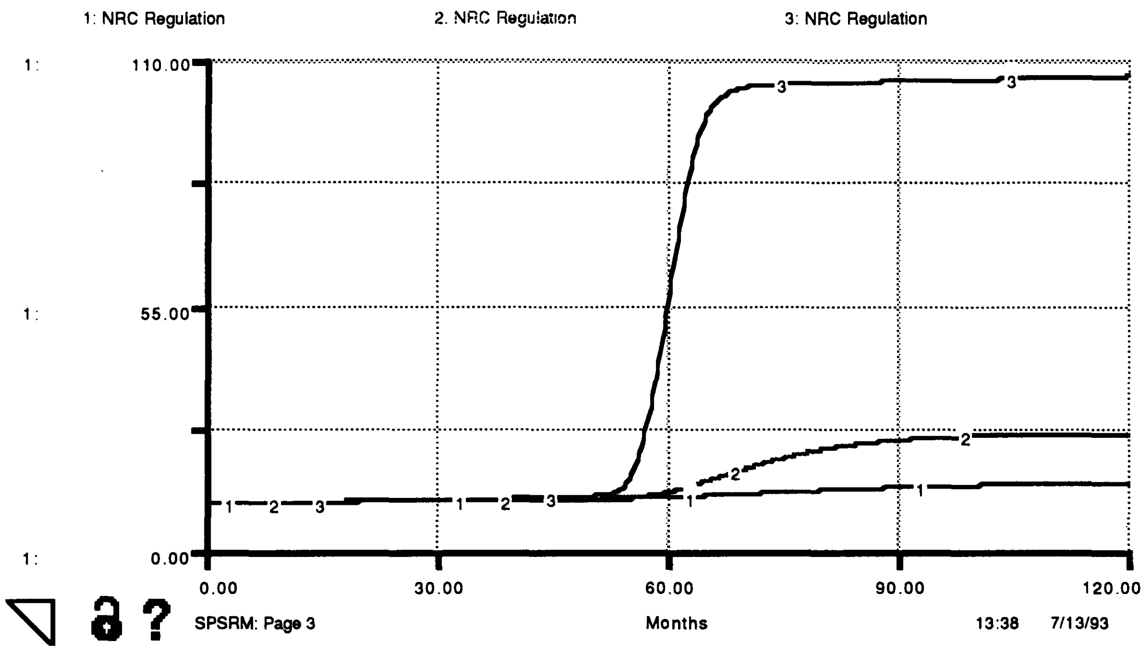

Figure 4.27: NRC Regulation
Ave Pub Donation [.5, 1, & 2]

The average public donation affects the system primarily through the level of interest group resources, but in so doing, it also alters public concern since interest group activities directly influence public opinion. The positive feedback within this loop greatly enhances the impact of changes in public donations to interest groups, accentuating the impact on the NRC whether donations are increased or decreased.

4.3.3.1.4 Public Donating Fraction

No graphs are provided here since changes in the public donating fraction mimic changes in the average public donation.

4.3.3.2 Interest Group Sector

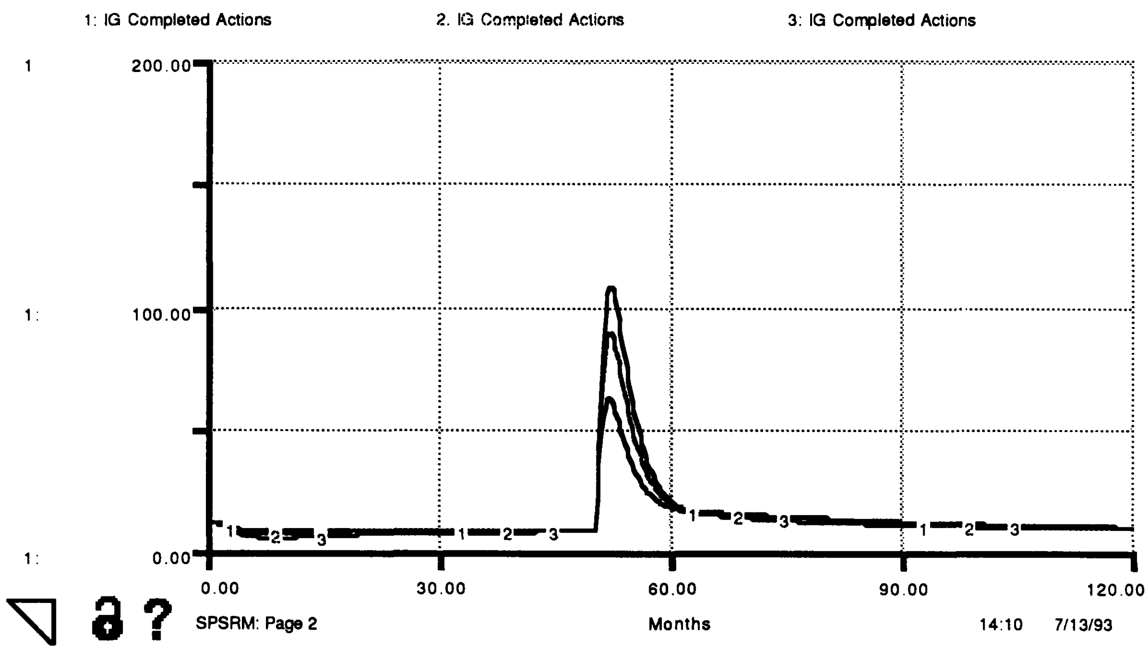

Figure 4.28: IG Completed Actions
Base Time [3, 6, & 12]

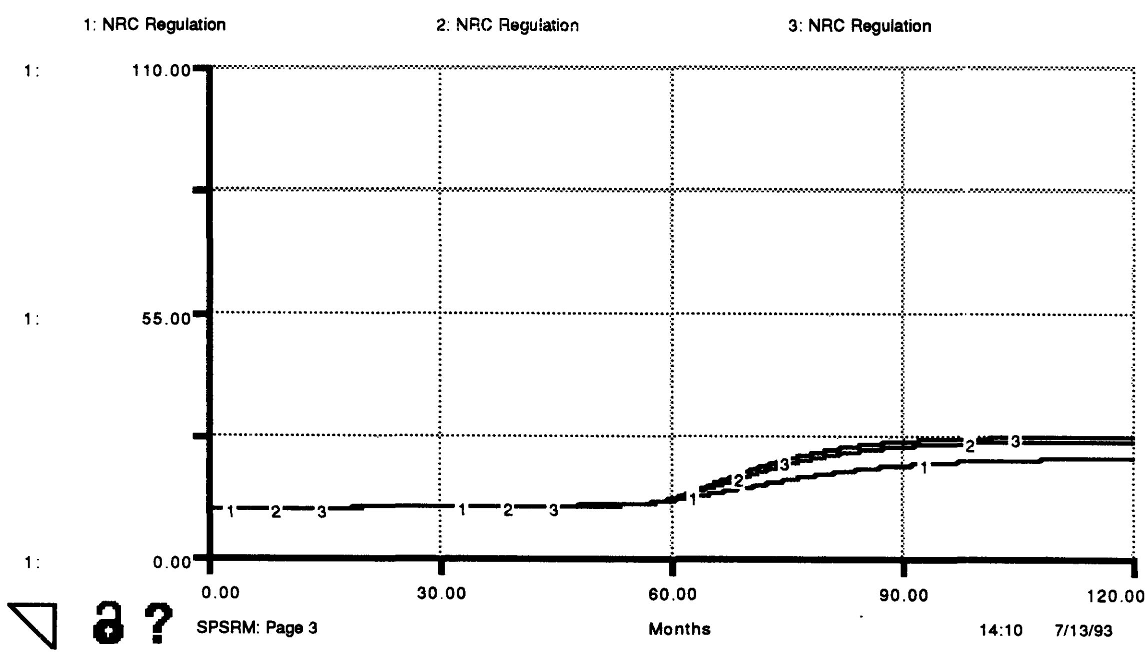

Figure 4.29: NRC Regulation
Base Time [3, 6, & 12]

Sensitivity runs indicate that changing governmental actions requires a significant boost in interest group completed actions. In the above graph Base Time ranges from 3 to 6 to 12 months producing a range of completed actions but little change in regulation.

4.3.3.3 Congressional Sector

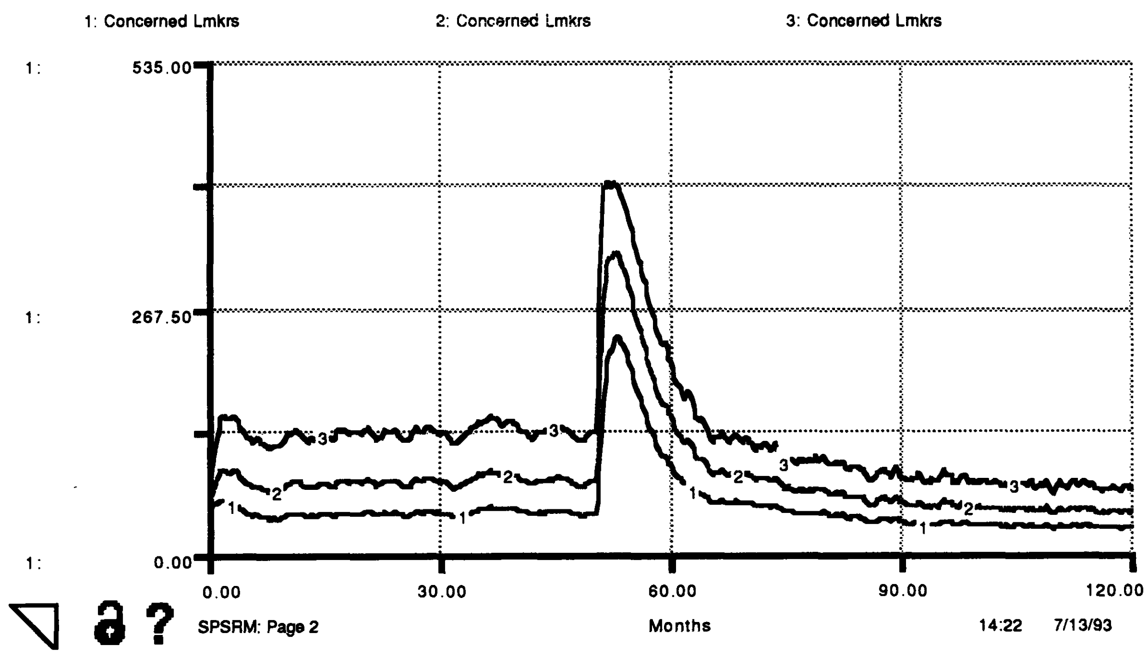

Figure 4.30: Concerned LMKR
C_Constant [.005, .01, & .02]

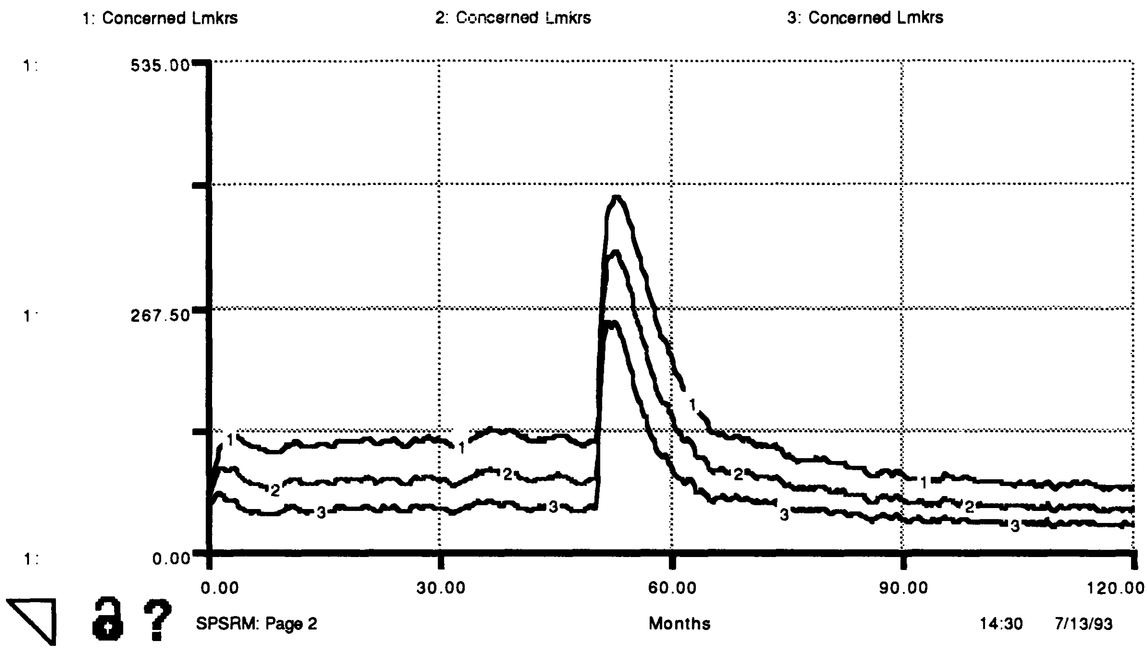

Figure 4.31: Concerned LMKR
SC_Constant [.05, .1, & .2]

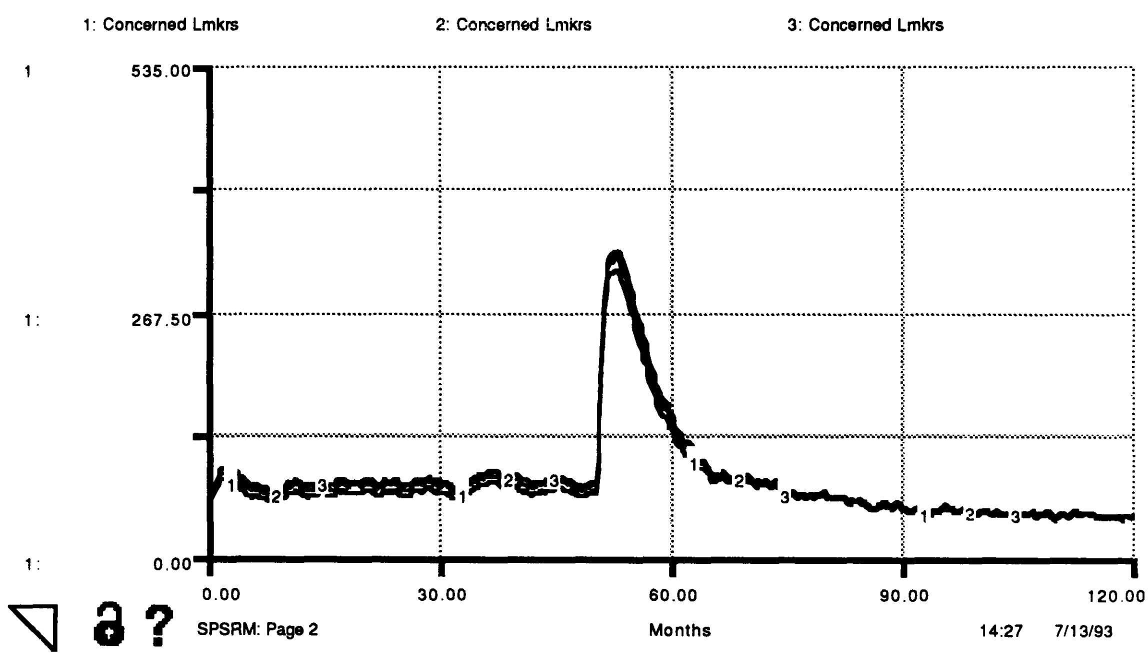

Figure 4.32: Concerned LMKR
C_Memory [6, 12, & 24]

Like the public sector, variables here guide Congressional converting and influence. The C Constant which specifies media, industry, and interest group influence, the SC Constant which specifies NRC influence, and C Memory which specifies the average span of lawmaker interest all guide converting, with the C and SC constants holding principle control. However, even with relatively large swings in Concerned Lawmakers, only a limited impact carries through to changes in governmental regulation (Figures 4.33 and 4.34 below). If this seems in error, note that the time of peak concern is generally of insufficient duration to develop and pass new legislation which might significantly alter regulatory practices. Personal pressure, not legislation, is in action here.

The Active Frequency and Active Fraction, although not shown here, do contribute significantly to Congressional influence upon the NRC. A doubling of either term would double influence. Since concerned lawmakers already (normal setup) peaks at over fifty percent, for converting to wield a similar impact on NRC actions the average duration of concern must increase: i.e. pressures which cause concern must last.

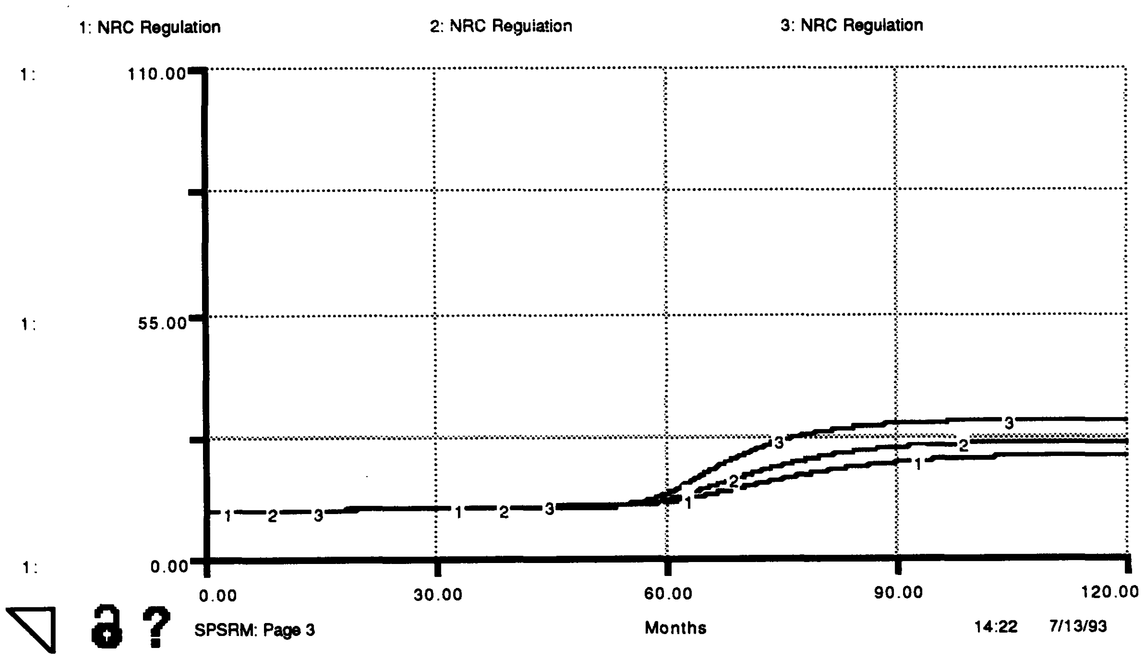

Figure 4.33: NRC Regulation
C_Constant [.005, .01, & .02]

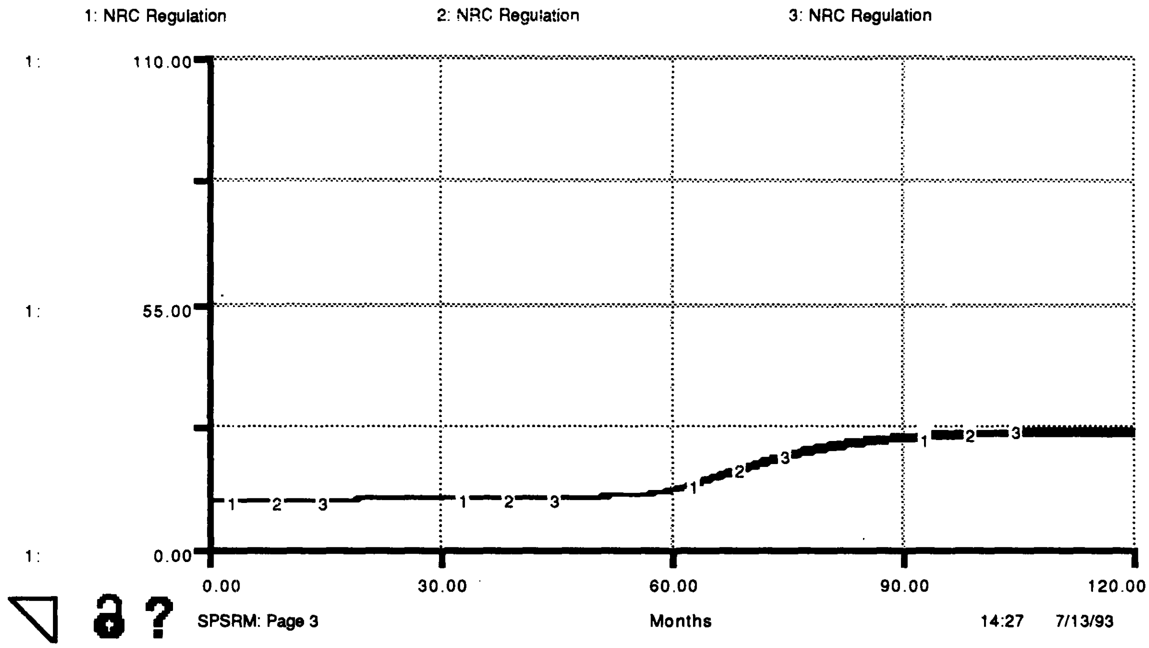

Figure 4.34: NRC Regulation
C_Memory [6, 12, & 24]

4.3.3.4 NRC Sector

Upon the NRC, constant parameters specify how factors affect concern and the speed of work. Time constants which define the rate of inquiry, reporting, and regulation must vary significantly more than here to drastically alter the quantity of actions performed (not shown). However, the NRC Constant, which specifies the influence of external factors, and NRC Action Influence Time, which specifies the influence of NRC actions, both wield substantial influence upon NRC concern and significantly impact regulatory actions. Regulatory actions are impacted more by the action influence time because NRC actions are the primary path for lowering concern -- the more time between action and dissipation of concern, the more time for concerns to initiate even more actions. A negative feedback loop exist between concern and action, the strength of which is defined by NRC Action Influence Time.

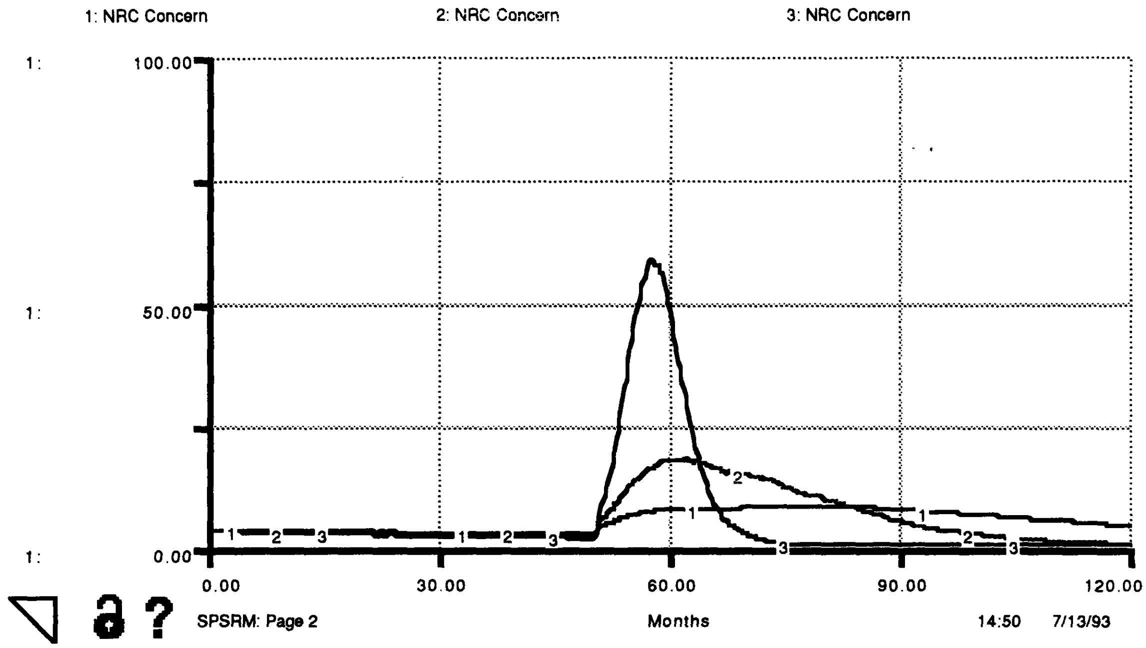

Figure 4.35: NRC Concern
NRC_Constant [50, 100, 200]

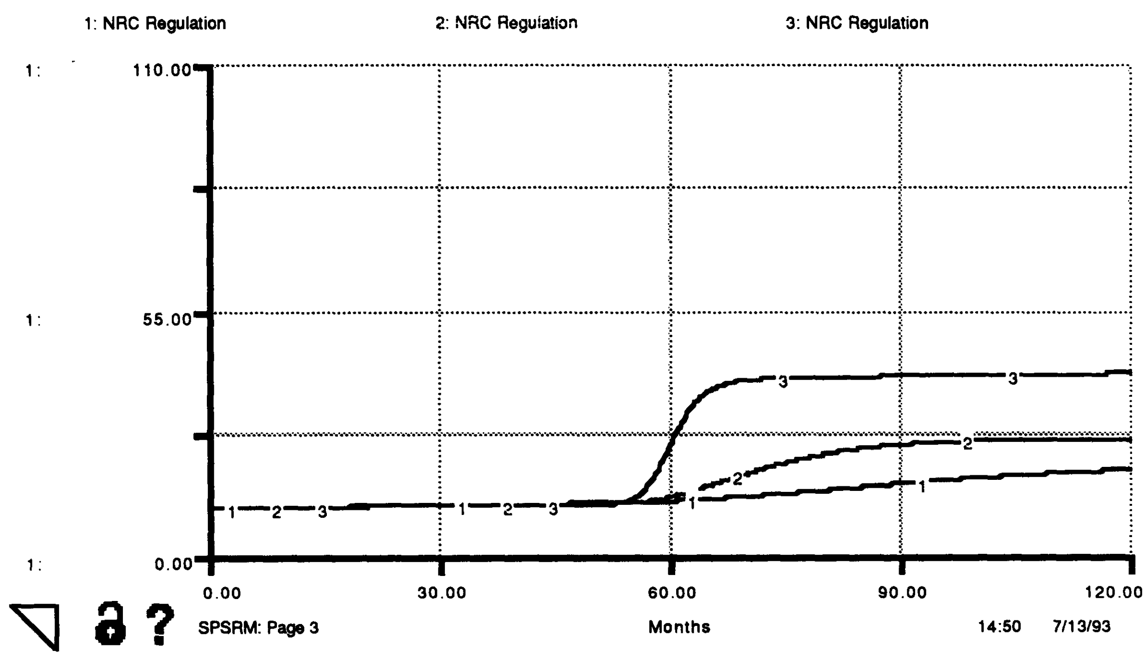

Figure 4.36: NRC Regulation
NRC_Constant [50, 100, 200]

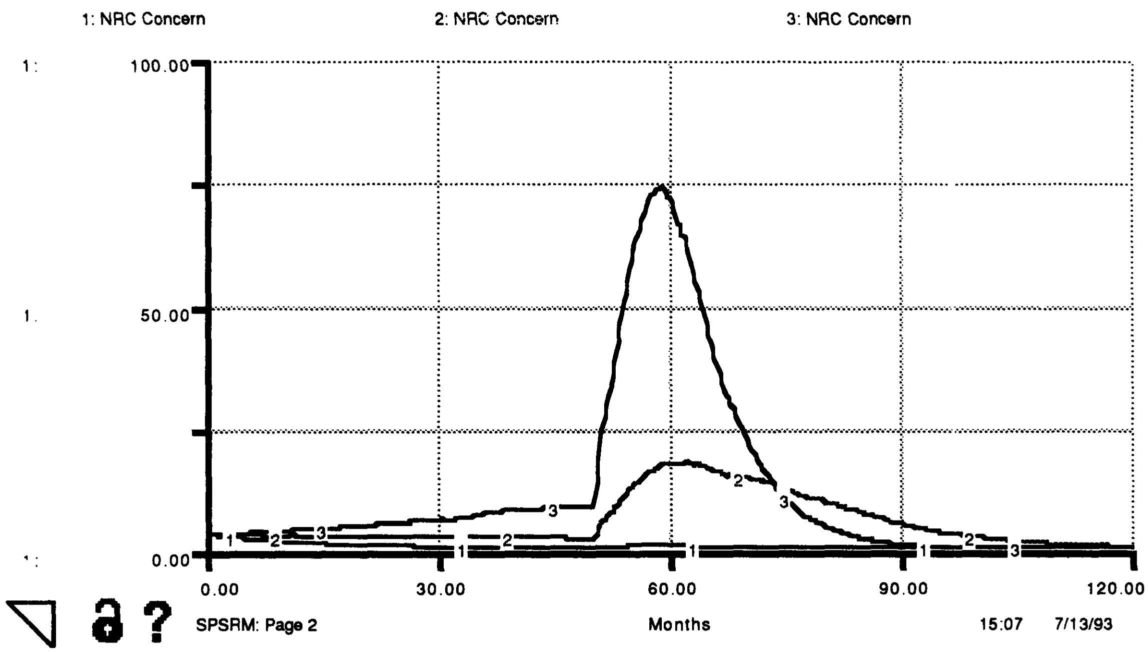

Figure 4.37: NRC Concern
NRC Action Influence Time
[1, 2, & 4]

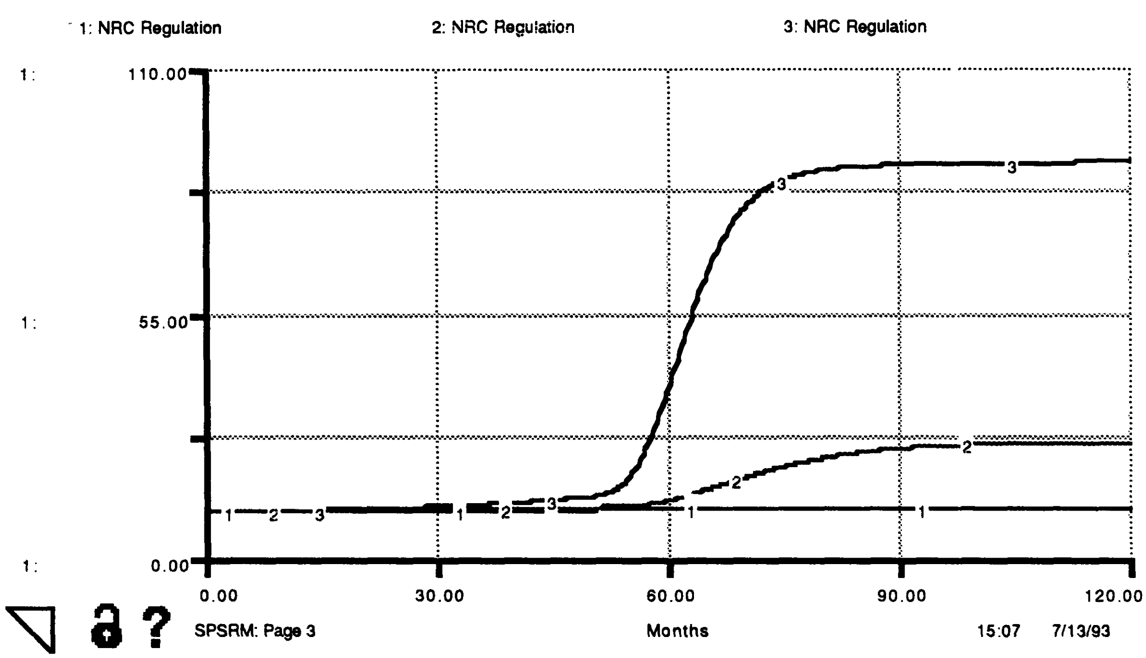

Figure 4.38: NRC Regulation
NRC Action Influence Time
[1, 2, & 4]

Chapter 5

5.0 Policy Implications

Policies are the laws, regulations, rules, and common practices with which government, industry, and individuals structure their actions. Each day, organizations and individuals function by making choices: what to produce, how much to produce, how to communicate, what to communicate, when to operate, how to distribute resources, how to govern, etc. Generally, such choices are not random, but follow some structure. This may be formalized in terms of government laws and company rules or informal in terms of societal customs, individual habits, and corporate routines. System dynamics provides a tool for studying how these decision structures and rules affect social dynamics. Within the nuclear industry, such knowledge might foster the development of policies which lessen the antagonism between the public and industry while maintaining safety and generating electricity at competitive cost. Looking at industry policy is one purpose the Social Pressure, Safety Regulation Model. This chapter discusses some of the policy implications within the SPSRM.

5.1 Utility

In choosing to build and operate a nuclear power plant, electric utilities create an increased risk to public health and safety. Although good engineering and construction practices combined with diligent operation minimizes the potential for harm, many within the public fear nuclear power and feel that it is an unnecessary risk. In response, both to technical risk and public concerns, the federal government regulates the construction and operation of civilian nuclear facilities. Yet even with government oversight, public opposition to nuclear power remains and has had significant impact upon the industry. Recognizing not only public influence but also public concern and fear, how should the nuclear utility manage social responsibilities and interactions?

Within the SPSRM, the social system begins with the general public and ends with government regulation. Information about nuclear power from the utility and other sources motivates the concerned public to initiate actions which lead to regulatory changes. These changes directly affect the nuclear utility. However, this is a partial view; not only does the public respond to the nuclear industry but the industry responds to the public -- changing utility actions to address social concerns. These changes beget new social concerns beginning the cycle of action, reaction anew. However, the SPSRM does not encompass the utility's decision structure. That must be addressed by future studies. Here, utility's actions are exogenous, and reactions to the social system are neglected. This limits the usefulness of the model, but nevertheless, the SPSRM indicates how and where the utility might influence system behavior.

Utility efforts to influence public behavior and actions fall into two categories: active efforts to affect opinions and passive information provided to the public about utility performance. By virtue of being a nuclear plant operator, nuclear utilities believe nuclear power a credible option for generating electricity. They actively seek public, Congressional, and NRC acceptance of the viability of nuclear power and of their competence in operating a plant. These efforts occur through direct contact with each model sector and indirect interaction through the reporting activities of the media. Additionally, information about plant performance disseminates through the media, interest groups, and the utility, influencing public and government opinion. These opinions ultimately affect utility actions. Although the utility often acts in response to external influences, utilities control their own actions: how to direct public relations activities, how to structure interactions with the NRC, and how to operate the nuclear plant. Consequently, these are the points where the utility could manipulate its own structure and policies to ultimately affect the social system.

5.1.1 Public Trust

The operation of a nuclear plant does not occurs in a vacuum, but rather in a populated society. It is a hazardous activity, but one which is currently accepted by the majority of society. However, in allowing a utility to build and operate a nuclear power plant, society has certain expectations of the utility. The public expects that the utility will build and operate the plant safety (display a high degree of technical competence); that the utility will be truthful in communicating any hazards that the plant imposes; and that the utility will place the public's welfare above its own financial gain.(Barber 1983) In an open, democratic society, there must be a degree of trust for society to allow a utility, or anyone else, to build and operate a nuclear power plant. However, trust, or a degree of distrust, is also why society demands regulation of such hazardous activities and why many within society actively seek to halt or alter nuclear operations.

Is distrust within society justifiable? Utilities may feel slighted or wronged by public opposition, but a realistic assessment of history and human behavior might indicate that questioning the motivations and technical competence of those who place one at risk is generally prudent behavior. If this is accepted, policies targeted at lessening social friction would focus on building and maintaining public trust. This seems most likely to follow from consistent examples of competence and frankness. If the industry claims immunity from mishaps and then they occur, trust will be difficult to recapture. Openness about risk, mishaps, and solutions can demonstrate a utility's understanding of public risk and their acceptance of responsibility to assure safety. Public trust should never be a given. Utility actions will probably always be questioned, and maintaining public trust will probably require continuos reassurance.

Public trust within the SPSRM is not dissaggregated as such but is represented in the public constant term which correlates utility public relations to public conversion. A skeptical public distrusts the utility and places more weight on intervener and media activities. If the utility could build and maintain trust, then with time public opposition might dissipate.

5.1.2 Group Interventions

Because groups typically exert more political clout than the individual citizen, people with common concerns routinely band together to further their common cause. Many such groups, both pre-existing and newly formed, express interest about the nuclear power industry. Most of these groups oppose nuclear power in general or have unique concerns over a particular plant.

The SPSRM utilizes interest groups as the only means for the public to act on social concerns. It also provides limited means for utilities to interact with or respond to interest groups. Utilities affect interest group activities only through performance. In a sense, interest groups rally around nuclear events because such incidents visibly demonstrate their concerns. Reducing or eliminating events is the only means within the SPSRM for utilities to directly deal with interest groups. An alternative path for influencing intervener groups exists through the public, since the public directly supports interest group formation and activities. As discussed in the previous section, to influence the public, utilities must gain public trust. If the public believes that the utility is both committed to public safety and competent to operate a nuclear plant, then they might express fewer concerns. Here again, public trust provides the foundation for social harmony with the utility. The public must believe that safe nuclear power is feasible, that the utility is competent to operate a safe plant, and that the utility will do so. It takes continuous and consistent exhibition of competence and openness to gain such trust. Maintenance of this trust may be the most effective means to counter interest group activities.

5.1.3 Regulation and Oversight

How the utility responds to regulations is not covered by the SPSRM. Still, the interactions between the NRC and utility affect the cost of operation and, if not the actual safety, certainly the perceived safety of the nuclear plant. Consequently, strategies for dealing with regulation and regulators are paramount in nuclear operations.

Actual regulation of a nuclear plant occurs in a variety of fashions. Federal Codes specify required actions by both the NRC and the utility; technical specifications approved by the NRC bind the plant to certain operating conditions; the NRC creates new operating requirements through Notices, Bulletins, Generic Letters, etc.; and NRC inspectors may require changes if practices, procedures, or other items are identified as insufficient during inspections. Requests or requirements from the NRC may be specific or general: identifying a required action or requesting a utility plan to address concerns. Either way, the utility is responsible for all NRC concerns. Of all forms of regulation, NRC inspections are the most open-ended. During inspections, NRC inspectors may inquire about almost any aspect of the plant.

Although the NRC acts to assure safety, many utilities complain that responding to regulatory inquiries and actions can drain significant resources and have questionable impacts on plant safety. Answering questions and inquiries before, during, and after inspections takes time and pulls engineers and staff away from other projects. Developing, negotiating, and implementing responses to bulletins, generic letters, and other issues also requires significant efforts in time and resources. If the utility questions the relevancy of NRC stipulated improvements in safety or operations, what resources should a utility apply toward satisfying the NRC? How will utility actions affect NRC relationships, and how will this affect future regulatory actions? How will utility actions toward the NRC affect relations with the public and interest groups? Will such actions affect safety, performance, or cost?

Utility response to the NRC is a significant policy choice which affects social behavior. Coefficients within the SPSRM such as the Public Constant, Congressional Constant, and NRC Constant depend upon relationships and interactions. These are the variables incorporate trust and acceptance of various actors and actions. Better relations with the NRC might move these variables in the utility's favor. However, because the utility's response to these interactions is not within the scope of this thesis, the above questions will remain open until further research can be performed.

5.1.4 Media

Information shapes public opinion, which guides social action. Consequently, how the media represents the nuclear industry is of great importance to utilities. Unfortunately for the utility, what makes news tends to be the unusual event or accident, not the well functioning plant. Even so, how the utility relates to the media and how media perceives the utility will affect the manner in which stories are presented.

With the media, as with other groups the utility interacts with, trust plays an important role. Reporters often distrust the words of utility representatives, believing the utility's story is generally biased. Consequently, when reporting the news, more weight may be given to other sources, leaving the utility perspective out. The utility may never eliminate a bias in presenting plant information, but it might improve it's credibility. Relationships with the press hinge on plant performance and how the utility presents performance. If the plant's performance is poor, the press will question the utility's competence in running the plant, even if the utility is honest with operating information. The utility must operate the plant safety and then be candid about operating information, both positive and negative. The press may not expect a perfect plant, but the press, like the public, expects problems to be dealt with effectively. Being open about operating concerns in addition to actions which address them might build stronger relationships with the media. Such relationships are necessary if the utility expects favorable representation within the public media.

5.1.5 Utility Policy Review

The primary purpose of creating the SPSRM is to study how the social system reacts to the operating nuclear plant. Yet, this reaction also affects the future plant operations. Consequently, how the utility interacts with the social system becomes quite significant for nuclear operations.

No matter how safe a nuclear plant is, it still presents some risk to public health and safety. It is this risk, and the distrust that the utility can or will adequately address this risk, that feeds social concern with the nuclear industry. Consequently, if a utility undertakes the construction and operation of a nuclear plant and expects the public to support this endeavor, it must demonstrate not only to the NRC but to the public that it can safely operate such a facility. This requires policies which continuously and consistently demonstrate the general safety and feasibility of nuclear power, the utility's competence to operate a plant, and the utility's placement of public safety over private gain. Public support will follow only when the public trust that the utility can and will operate a nuclear plant safely.

Chapter 6

6.0 Summary and Conclusions

In the early years of the commercial nuclear industry, when swords were being transformed into plowshares, nuclear power promised to one day dominate electricity generation. Perhaps it will, but that time has yet to come to pass. Even though nuclear reactors produce steam for generating approximately twenty percent of the United States' electricity needs, the industry appears to have stagnated. Financial and social constraints have brought the nuclear crusade to a stand-still. During the early years, the 1950s and 1960s, commercial nuclear power appeared to have significant public support. The Federal Government encouraged commercialization of nuclear technologies and financed research and development efforts. However, by the 1970s, public opposition to nuclear power was a significant force, and following the Three Mile Island Incident, social constraints from public and government intervention drastically altered the development and operation of the nuclear industry.

The concerns that have driven public opposition to nuclear power find their origins in both the technical realities of nuclear technologies and the psychological and social uncertainties connected with nuclear energy, modern warfare, and social power. Inherent to the utilization of fissionable materials for generating electricity, providing medical care, or any other use, is the presence of radioactive matter and the release of small quantities radiation. Radiation presents a real threat in that significant doses can kill or harm humans and other living organisms. In addition to the fear that radiation will emanate from power plants, nuclear technology can elicit fears associated with nuclear bombs, such as the horrors of Hiroshima and Nagasaki. Although power plants cannot explode like a nuclear bomb, the psychological association and imagery persist. The security and secrecy that have traditionally followed nuclear technology seem to only enhance such fears. A consequence of these public concerns is a citizenry that distrust most anything associated with nuclear technology, giving the commercial nuclear industry a poor imagine and ultimately leading to significant social constraints.

The question this thesis has raised is whether the interactions between the public and the nuclear industry result in a net positive benefit. Public concerns drive public actions directed toward altering nuclear plant construction or operation. Responses to this public action from the nuclear utility may appease the public's concern or create more concern leading to additional public action requiring additional utility response and so on and so on, creating a loop of action and reaction with uncertain consequences. Making the consequences even more uncertain is the fact that the constraints created by the public and the responses developed by the nuclear utility may take years to display a benefit, or lack thereof. Consequently, the complexity and delays of the connections and feedbacks between the public domain and the nuclear utility make it extremely difficult, if not impossible, for the unaided mind to assess, let alone predict, the impacts of social interactions upon the nuclear industry.

The Social Pressure Safety Regulation Model recognizes the complexity of the public's interactions with the nuclear industry. It is this complexity that the SPSR model seeks to emulate. The structures and policies actually incorporated in the SPSRM represent the perspectives and mental representations of individuals from both the nuclear industry and from several social organizations that interact with the nuclear utility.

Simulations of the SPSRM demonstrate the non-intuitive behavior of dynamic systems. The social pressure safety regulation system was simulated with a nuclear plant event, on the order of a Three Mile Island Incident, exogenously inputted to the model. Public concern immediately rose as might be expected, but died out relatively quickly. Interest group activities spiked following the event, again dying out relatively quickly (a few months). With public pressure being so short lived, one might expect a relatively minor reaction from Federal Regulatory Agencies, the NRC. However, what the event and public pressure did was to initiate a series of actions which then took years for maturation. NRC concern rises immediately causing the agency to initiate numerous projects. Legal requirements begin to change approximately a year following the event and continue for four or five more years. Consequently, the bulk of regulatory changes occur almost four years after the incident, long after the public has forgotten their concerns over the event. The SPSRM demonstrates that cause and effect may not be immediately apparent. After a year, a concerned public may have concluded that the NRC did little in response to the event, eroding their confidence in the government's actions. However, the utility seeing the influx of regulatory changes three or four years later may conclude the NRC excessive in their regulatory responsibilities.

The model presented within this thesis concentrates on the public's ability to influence the development of governmental regulation and assumes that is the only social driver influencing the nuclear utility. However, it is recognized that other pathways for influence exist. For example, questions such as how the public may influence the financial resources available to the nuclear utility or how the public may directly affect the perspectives and attitudes of individuals working in the nuclear industry are potentially relevant but have been left for future research efforts. Despite the limited scope, the SPSRM does indicate that a more enhanced model could provide greater insight into the mechanisms through which the public alters nuclear plant performance.

Given the uncertainty of future energy supplies and the potential role of nuclear power in supplying these needs, it would benefit society to have a better understanding of the impact of the public's involvement with the nuclear utility and the appropriateness of the nuclear utility's response to that involvement. Nuclear fission represents one alternative for meeting society's energy demands. Although it is an alternative which has inherent hazards and risk, environmental or resource concerns may make nuclear fission one of a few viable options for generating electricity at a reasonable cost in significant scale. If nuclear power is to remain a presence in the world, it would be in society's interest to maintain the safest industry possible. Understanding how public concerns influence the industry is paramount in this effort.

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